# THE NICKEL BULLETIN

## A MONTHLY SUMMARY OF CURRENT INFORMATION

JANUARY-FEBRUARY, 1956


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VOLUME 29 NUMBERS 1-2

THE MOND NICKEL COMPANY LTD • THAMES HOUSE, MILLBANK, LONDON, S.W.1
Telephone:– Victoria 3888

# ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

## GENERAL

### A.S.M. Metals Handbook: Revised Sections*

The revised sections of this Handbook, first published as the Aug. 15, 1955, issue of *Metal Progress*, have now been made available in book form (200 pp. + index). The volume is obtainable from *The American Society for Metals*, 7301 Euclid Avenue, Cleveland 3, Ohio. Price: A.S.M. Members, 4 dollars; Non-Members, 5 dollars

### Vacuum Metallurgy: Symposium

'Vacuum Metallurgy. Papers presented at Symposium of the Electrothermics and Metallurgy Division of The Electrochemical Society, Oct. 6-7, 1954.' Published by *The Electrochemical Society*, 1955; 213 pp.

A foreword to the symposium points out that although vacuum technique has been for some years recognized as a research method of importance in metallurgy, recent development has been in the direction of application of such procedures to large-scale production and treatment.

The scope of the individual contributions is shown below:—

J. D. NISBET: 'The Bright Spark in the Metals Industry', pp. 2-11.

An outline of the gradual development of the idea of vacuum melting, as an aid to the perfection of product which is the aim of every metallurgist.

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P. C. ROSSIN: 'Arc Melting in High Vacuum', pp. 12-23.

Arc melting in its modern sense comprises the process of consolidating highly reactive or refractory metals by fusion within inert media. Melting is effected in a water-cooled metallic mould, by the use of a high-current arc. The melting crucible is adapted to the furnace body, forming a closed system. Inert gases or vacuum conditions are used to reduce the partial pressure of contaminant gases, and it is emphasized by the author that arc melting in high vacuum (less than 1 mm. Hg) requires a more meticulously controlled balance of component sizes and power than is required when using inert gases. The factors involved in maintenance of arc stability and control are considered in this paper, and their influence on melting practice is discussed. A qualitative analysis is made of the thermal equilibrium associated with the cathode, arc column, anode, and mould-metal interface.

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H. R. SPENDELOW, I. S. SERVI and G. A. FRITZLEN: 'Vacuum Melting of High-Alloy Materials', pp. 24-34.

Although it has been increasingly realized during the past decade that vacuum melting offers promise as a means of improving the properties of high-alloy materials, the published literature is, with few exceptions, of a somewhat general nature, containing little direct comparison between the properties of vacuum-melted materials and those produced by other methods.

The precise aim of this paper is to demonstrate the influence of vacuum melting on the properties of titanium- and aluminium-containing nickel-chromium-base alloys, taking, as representative, the material known as Hastelloy R-235, which is of the following composition: chromium 15, iron 8, molybdenum 5·5, titanium 2·5, aluminium 2·0, carbon 0·15, per cent., balance nickel. The conclusions drawn are based on tests made on more than one hundred alloys conforming broadly to this range.

With regard to production conditions, it is noted that the charges consisted of commercial materials, except that aluminium and titanium were in many cases added in the form of special master alloys. In most cases the raw material was mixed before charging, but minor additions were made in vacuo, to adjust chemical composition. Refining and pouring temperatures were about 1500°C., and cast-iron ingot moulds were used. The ingots were forged at usual commercial hot-forging temperatures, and rolled to $\frac{9}{16}$-in. rounds.

Mechanical testing comprised room-temperature short-time tensile tests, and stress-rupture tests at temperatures in the range 1500°-1800°F. (815°-980°C.). Visual observations were made (by a specially developed method) to determine the influence of vacuum melting on the susceptibility of this type of alloy (when melted in air) to formation of large clusters of inclusions. Specimens electrolytically etched in dilute fluoboric acid solution were subjected to metallographic examination, and gas analyses of vacuum- and air-melted heats of the alloy were also carried out.

Part I of the paper reports experimental laboratory work: Part II carries the method through to a production scale, using 500-lb. heats.

The results of both investigations are considered to justify the conclusion that the following advantages are obtained by vacuum melting:—

(1) Decrease in oxygen and nitrogen contents, and elimination of large clusters of inclusions. Closer control and better recoveries of alloying elements.

(2) Better hot-workability, and increased ductility at elevated temperatures.

(3) Increased stress-rupture lives.

(4) Possibility of full utilization of scrap.

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J. L. HAM and F. L. CARR: 'Impact Properties of Vacuum-Melted Iron-Chromium Alloys', pp. 35-48.

The paper records investigations on a series of

**See Nickel Bulletin, 1955, vol. 28, No. 12, p. 205.*

binary iron-chromium alloys containing 0-49 per cent. chromium and small but accurately known amounts of carbon, oxygen and nitrogen. Standard V-notch Charpy impact tests were made, at precisely controlled temperatures. The results indicate that vacuum melting is advantageous, both for pure iron and for the alloys examined. The nature of the improvement so effected is evaluated by reference to the properties of commercial chromium steels of comparable chromium content.

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H. A. SALLER, R. F. DICKERSON and E. L. FOSTER: 'Vacuum Induction-Melted Zirconium and Zirconium Alloys', pp. 49-60.

Hardness at temperatures up to 800°C., drawability, electrical resistance, corrosion-resistance and tensile properties were evaluated, on vacuum-melted zirconium and zirconium-tin alloys. Microstructural examination was also made.

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E. R. MORGAN and D. N. FREY: 'Vacuum and Pressure Melting of Iron-base Alloys', pp. 61-6.

This paper is essentially a review of operating experience and techniques of alloy development which have been developed in the Scientific Laboratory of The Ford Motor Company. Much of the information given is generally applicable to iron alloys, and specific reference is made to production of high-purity iron-boron alloys (for use as spectroscopic standards), and to elimination of gaseous contamination in iron-aluminium alloys by means of vacuum melting.

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R. F. DOMAGALA and D. J. McPHERSON: 'The Design and Operation of an Induction and a Resistance Furnace for High - Vacuum/High - Temperature Applications', pp. 67-71.

The furnaces described are improved modifications of units which have already been described in the literature: the specific aim has been to ensure convenient and trouble-free operation and ease of repair. Such models are stated to be extensively used for determination of melting points of alloys, and for heat-treatment at temperatures of 1500°-2500°C. under high-vacuum conditions.

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W. R. McMILLAN and E. A. GULBRANSEN: 'A New Method for the Evaluation of High-Vacuum Furnaces and Heat-Treating Atmospheres', pp. 72-85.

In connexion with the refinement of atmospheres and improvement of vacua called for in modern heat-treatment, the authors give an account of laboratory tests on oxidation of two grades of high-purity iron in high vacuum ($10^{-7}$ mm.Hg) and in oxygen atmospheres of $1 \times 10^{-5}$ mm. Hg.

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C. N. VAN ATTA and R. L. SYLVESTER: 'Theory and Performance Characteristics of a Kinney Mechanical Booster Vacuum Pump', pp. 86-93.

The Kinney pump, which is described as 'a radically new type of positive-displacement unit', is used as a high-vacuum stage in the low-pressure range in which the volumetric efficiency of a single-stage vacuum pump drops.

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T. E. BURLEIGH and W. C. FRYE: 'Rotary Gas Ballast Pumps', pp. 94-6.

The paper comprises an explanation of the gas-ballast principle, introduced by The National Research Corporation into the U.S.A. The principle of gas ballast was developed some twenty years ago by Gaede, one of the pioneers in high-vacuum technique in Germany.

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C. J. CRITES: 'The Economics of Vacuum Melting', pp. 97-9.

A considered presentation of the practical pros and cons of vacuum melting.

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W. F. MOORE and R. K. McKECHNIE: 'Deoxidation of Vacuum-Melted M-252', pp. 100-5.

Although elimination of exterior atmosphere is a substantial aid in deoxidation, such procedure is not sufficient safeguard against formation of gaseous inclusions, since the raw materials used are also a source of oxygen and nitrogen. Hence the need for deoxidation, even when melting is done in vacuo. This paper reports investigation of deoxidizing media and methods for use in production of M-252, an alloy of the following composition: chromium 18-20, cobalt 9-11, molybdenum 9-11, titanium 2·25-2·75, aluminium 0·75-1·25, carbon 0·10-0·20, per cent., nickel balance. Examination was made of vacuum-melted material which had not been deoxidized, of the same material hydrogen-treated, and of heats in which the following deoxidizers had been used under varying conditions of addition: manganese, calcium, aluminium, cerium, aluminium+cerium, titanium, manganese+silicon, calcium+manganese+silicon.

Analysis of the heats variously treated shows that the oxygen content of such an alloy is reduced by about 20 per cent. if the bath is deoxidized by hydrogen before the titanium, aluminium and carbon are added. Solid deoxidizers and hydrogen were found to be equally effective with regard to final oxygen content in the range 0·0004-0·001 per cent. oxygen. If the deoxidation is accomplished solely by the reactive addition agents titanium, aluminium and carbon, the final oxygen content is greater by a factor of two than if an additional deoxidizing step precedes such additions. As rated by upset tests, all vacuum-melted heats were satisfactory.

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R. L. HADLEY and L. M. BIANCHI: 'Hydrogen Deoxidation of Vacuum-Melted High-Temperature Alloys', pp. 106-21.

One of the advantages of vacuum melting is that it permits reduction of the oxygen content of the melt by the use of hydrogen. Residual hydrogen can be removed after deoxidation, and a deoxidized product is thus obtained without recourse to metallic deoxidizing elements. The investigation reported in this

paper was concerned with the hydrogen-deoxidation phase of the process and the factors on which its effectiveness depends. Materials used as representative were iron, nickel, and cobalt, and, since chromium is an important constituent in many alloys to which vacuum melting is applicable, binary alloys of the three metals, containing 10 and 20 per cent. of chromium, were also used. Consideration was given to the following variables, as likely to influence deoxidation: (1) temperature, (2) hydrogen dew point, (3) hydrogen pressure, (4) flow rate of the hydrogen, and (5) composition of the material treated.

From the results obtained the authors conclude that—

(*a*) Deoxidation by a stream of dry hydrogen impinging on a molten metal surface is capable of reducing the oxygen content of iron, nickel and cobalt to below 0·005 per cent. at 1570°C., under conditions applicable to large-scale vacuum melting.

(*b*) Addition of chromium to any one of the three metals increases the amount of oxygen present in the alloy after hydrogen treatment.

(*c*) The extent of deoxidation is limited by the relation between the rates of removal of oxygen by hydrogen and the rate of its supply from the melting crucible.

(*d*) The deoxidation process is relatively insensitive to pressure, flow rate, time (after approximately 10 minutes), and atomization of hydrogen.

(*e*) Re-oxidation of small melts during evacuation of hydrogen prior to casting tends to nullify deoxidation below 0·002 per cent. of oxygen.

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R. G. ULRECH: 'The Application of Vacuum Technology to Metallurgical Processes', pp. 122–7.

The author describes his paper as 'an attempt to summarize and discuss, in a very general way, the application of vacuum techniques to all the types of metallurgical processes which have thus far appeared to lend themselves most readily to utilization of this new tool.' Within this broad outline, some consideration is given to the use of vacuum conditions in annealing, gases and gas-metal relationships, and melting and casting operations.

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R. L. HOFF and A. M. BOUNDS: 'Vacuum Heat-Treating Techniques', pp. 128–41.

In the introduction, some consideration is given to vapour pressures of metals and to the dissociation pressures of metal-gas compounds, as being two basic subjects which are significant in relation to vacuum heat-treating. This is followed by discussion of the essential units of vacuum heat-treating equipment: typical furnaces, pumping systems, etc., are illustrated.

The applications of vacuum heat-treatment and some results already achieved are then reviewed, with notes on variation of conditions dictated by the nature of the metals and alloys being treated. Examples are cited of improved properties which have been obtained in titanium and its alloys, and in chromium-iron-titanium alloys, and attention is directed to the benefits of vacuum treatment for precipitation-hardening nickel-base alloys. Evaluation tests are proceeding on vacuum-heat-treated nickel-base materials in electronic tubes.

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F. C. TODD, J. E. DRENNAN and W. W. KLEINSCHMIDT: 'Solid-State Purification of Molybdenum by Induction Heating', pp. 142–6.

For some years a study has been in progress in the Battelle Memorial Institute on discharges through noble gases: a practical objective has been to ascertain the most desirable combination of gases and electrodes for stable and reproducible voltage-regulator and voltage-reference tubes, which are employed in industrial electronic circuits to minimize the effect of fluctuations in the line voltage, on the reproducibility of functioning of the circuit. It has been established that extreme purity in both the gases and the electrode material is essential. The V.R. tubes are filled with noble gas of high purity, and after filling, the impurity content is lowered by sputtering metal from the electrodes. Molybdenum has proved to be the best getter for this application. This paper records that the molybdenum electrodes may be degassed by means of a solid-state-purification technique, which consists of heating the electrodes for at least 6 hours at about 1900°C. and at a pressure of $5 \times 10^{-5}$ mm. of Hg, or less.

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C. B. GRIFFITH and M. W. MALLETT: 'Vacuum Degassing of Titanium', pp. 147–54.

The deleterious effect of hydrogen, on the mechanical properties of titanium and titanium alloys, is already well known. The investigation reported in this paper was conducted to determine the optimum conditions for removal of hydrogen from commercial titanium. A temperature of about 815°C. was found to be best, from the dual standpoint of rapidity of degassing and minimum residual hydrogen content (solubility limit) for a given pressure.

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R. SPEISER and J. W. SPRETNAK: 'Determination of the Vapour Pressure of Metals and Alloys', pp. 155–91.

This paper is mainly concerned with a discussion of research on the vapour pressure of the elements carried out since 1950. Particular attention is devoted to dynamical experimental procedures which have in most cases been employed during that period.

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M. J. SPENDLOVE: 'Experiments on Vacuum Distillation of Non-Ferrous Metals and Alloys', pp. 192–213.

As part of the U.S. Bureau of Mines Conservation programme, the Eastern Experiment Station, College Park, Maryland has carried out a considerable amount of research on selective vacuum distillation, as a technique which could be generally applied in separating and refining metals, and particularly non-ferrous secondary scrap, dross, and residues. The information presented in this paper is selected, as representative, from previously published reports. Individual sections deal, respectively, with the

mechanism of evaporation, and with typical applications of vacuum distillation for separation of non-ferrous metals. The advantages and the practical difficulties of the method are indicated.

**The Vitron Process for Compacting Powders**

R. HUMPHREY, M. VILELLA and L. W. TOMARKIN: 'Uniform Density and Structure Possible with Simultaneous High Pressure and Temperature.'
*Jnl. of Metals*, 1955, vol. 7, Nov., Sect. 1, pp. 1159–61.

The Vitron process, which is described in this article, differs from known powder-metallurgical methods in that simultaneously the action of extremely high pressure and temperatures can be employed. Work already carried out has involved the use of pressures of the order of 40,000 atmospheres, with temperatures above 5000°F. (2760°C.). An advantage of the process is that chips, turnings, sponge and scrap, as well as powder, can be used as the starting material.

It is pointed out that the Vitron process is essentially hydraulic in action. With suitable metallic lubrication and spacing between the die holder and the dies and pressings, shrinkage of the compacted material during consolidation is radial as well as longitudinal: the forces acting on it are equal in all directions, giving a condition analogous to that of a solid immersed in a liquid system while subjected to pressure. The use of this hydraulic principle is considered to have two advantages: (1) pressings of greater length can be made, without the occurrence of substantial differences in physical structure from one end of a bar to another, and (2) the inconvenience of squeeze-out, bleeding, or segregation of any liquid phase or light constituent is eliminated. A further factor of importance is that the process is extremely rapid, a matter of seconds only; under the conditions of high pressure and temperature used, it is possible, for example, quickly to produce equilibrium conditions in stainless steels and other materials in which such a result is secured only after prolonged soaking at the sintering temperatures used in normal powder-metallurgy practice. The scope of the process is believed to be wide, including not only the production of solid objects, but cladding, and the processing of some materials which cannot be treated by other methods. Costs are claimed to be low.

Among the materials for the production of which the Vitron process has been successfully used are titanium, tungsten, and nickel-phosphorus alloys. The nickel-base alloys have properties of hardness and wear-resistance likely to be of outstanding service in many industrial applications.

**Nickel-containing Materials in Nuclear Power Plant**

'The Peaceful Uses of Atomic Energy.'
*Nucleonics*, 1955, vol. 13, Sept., pp. 34–101.

This issue contains a condensed but highly informative survey of the substance of some major papers presented at the International Conference held in Geneva in August 1955. The material is reviewed in sections relating, respectively, to world energy consumption and the distribution and regulation of nuclear power sources; design and operation of power and research reactors; reactor fuels; reactor materials; the physics involved in development of nuclear power resources. A list is given of the individual papers from which the summary is made.

In some of the contributions relating to materials for reactors and other items of nuclear power plant, reference is made to the use of nickel-containing steels and alloys, and the influence of radiation on properties is considered, as affecting the mechanical and physical properties of these and other metallic materials.

It is expected that the full record of the Conference will be available early in 1956.

**Machining Thin Sections**

See abstract on p. 17.

**Self-Discharge of the Negative of Nickel-Alkaline Accumulators**

See abstract on p. 7.

## NICKEL

**Extraction of Nickel from Philippine Ores**

L. H. BANNING and W. E. ANABLE: 'Preliminary Electric Smelting Research on Philippine Nickeliferous Ores.'
*U.S. Bur. Mines, Report of Investigations* 5129, May, 1955; 13 pp.

In connexion with investigations designed to supplement existing world supplies of nickel, the Philippine Bureau of Mines, under a Foreign Operations Administration Technical Assistance programme, has made a preliminary survey of areas on the island of Nonoc, to determine occurrence, distribution, and grade of nickel contained in the lateritic ores of that area, and in the adjacent serpentine. Simultaneously, consideration was given to the possibility of producing commercial ferronickel from nickeliferous materials found in the Philippine Islands. In 1954, after the preliminary reconnaissance, samples of Philippine ore were sent to the U.S. Federal Bureau of Mines Laboratory, for investigation of suitable smelting procedure.

The results of the tests detailed in this report, indicate that under suitable conditions, approximately 93 per cent. of the nickel can be recovered from these ores as a high-grade, low-carbon ferronickel product, and that about 35 lbs. of nickel can be recovered in this form from each ton of dry ore smelted. The tests have demonstrated the feasibility of using bagasse as a carbonaceous reductant for the selective reduction of this type of nickeliferous ore. This material, which is a by-product of the sugar industry of the Philippine Islands, would thus be put to effective use, whereas at present a large proportion of it is wasted.

**Estimation of Small Amounts of Nickel in Copper Ores and Concentrates**

A. LIBERMAN: 'The Determination of Small Amounts of Nickel in Copper Ores and Concentrates containing Iron and Cobalt.'
*Analyst*, 1955, vol. 80, Aug., pp. 595–8.

In the method described the ore is first treated with

dilute hydrochloric acid and gently warmed, so that a large proportion of the sulphur is eliminated as hydrogen sulphide. After complete solution of the sample with perchloric acid, the metals of group II are precipitated with hydrogen sulphide and filtered off with the silica. The filtrate is made 8*N* with respect to hydrochloric acid and passed through a strong-base anion-exchange column; the nickel in the effluent is determined colorimetrically by the hypobromite-dimethylglyoxime method. The procedure has been applied with satisfactory results to sulphide and oxide copper ores and their concentrates.

**Heating of Nickel and Nickel-Clad Steel: Recommended Procedure**

MOND NICKEL CO., LTD.: 'The Heating of Nickel and Nickel-Clad Steel.' *Publn. No.* 910, 1955; 47 pp.

During recent years an increased demand has developed for large plant constructed in nickel, and in this connexion heating operations of various kinds are necessarily involved. Experience has emphasized the fact that in heating nickel it is essential to take certain precautions with which some workshops may not be generally familiar. The information presented in this publication has been gathered, over a period of years, from a number of fabricators and users of nickel plant, who have contributed their experience with nickel and nickel-clad steel, and this is supplemented by evidence obtained in extensive laboratory investigations.

The publication is of an essentially practical character, comprising precise and detailed recommendations on heating procedure, and a well illustrated description of defects which may result from incorrect heating. The scope of the information given is shown below:—

(1) Attack by sulphur and oxygen on heated nickel.
(2) Contamination of nickel before heating, e.g., by the atmosphere, during handling, by grease and oil, or during fabrication.
(3) Cleaning procedures immediately prior to heating.
(4) Contamination during heating, e.g., by products of combustion, etc.
(5) Precautions to be observed during the heating of nickel for hot-forming, annealing, stress-relief, and welding.

In a summary of practices used in some of the leading European workshops in which nickel is being handled, it is noted that in the majority of cases sulphur-free furnace conditions are not available, and that compromise measures are adopted to ensure minimum danger of damage to the metal processed. Some essential points of technique adopted by four different fabricators are reviewed.

**Summary of Recommendations for Heating Nickel**

*Attack by Sulphur and Oxygen*

Nickel has an affinity for sulphur and is embrittled when heated to temperatures as low as 500°C. in contact with sulphur or sulphur compounds in any gaseous, liquid, or solid form. Sulphur is found in atmospheric condensation, in most fuels, oils, greases, paints, and in many other materials common to stores, workshops, etc.

When heated for long periods at high temperature in oxidizing atmospheres the surface of nickel is embrittled by intergranular oxidation.

When nickel is heated in an oxidizing atmosphere containing sulphur at temperatures below about 900°C., sulphur attack will occur, but at higher temperatures oxidation occurs.

The damage may not appear until the nickel is worked.

*Contamination*

The surface of nickel can become contaminated by sulphur compounds normally present in the atmosphere; this contamination must be removed before the nickel is heated.

If handled carelessly, nickel surfaces become contaminated with oil, grease and other sulphur-containing materials. Nickel must be degreased before the atmospheric contamination can be removed.

*Cleaning*

Oil and grease must be removed by the use of solvents or chemicals. Atmospheric contamination can be removed by the use of abrasives or by acid swabbing. All cleaning must be effected immediately before heating.

*Contamination during Heating*

Nickel can be contaminated during heating as a result of sulphur in the fuels or the furnaces used.

Fuels must be of low sulphur content: gas less than 10 grains of sulphur per 100 cu. ft.: oil preferably less than 0·2 per cent. sulphur content. Use slightly oxidizing atmosphere.

*Heating of Nickel*

When heating for hot-forming, heat rapidly, and use working equipment of power sufficient to minimize the number of heatings.

When heating for annealing or stress-relieving, heat rapidly, hold 10 minutes at temperature, cool rapidly.

Prior to welding, clean metal for 1 in. on each side of weld. Remove slag before heating subsequent to welding.

**Adsorption of Argon on Oxide-Coated and on Reduced Nickel**

A. C. ZETTLEMOYER, Y.-F. YU and J. J. CHESSICK: 'Adsorption Studies on Metals. IV. The Physical Adsorption of Argon on Oxide-Coated and Reduced Nickel.'
*Jnl. Physical Chemistry*, 1955, vol. 59, July, pp. 588–92.

Isotherms for the adsorption of argon on oxide-coated nickel powder and on the same sample after each of several reductions with dry hydrogen, at 350°C., were determined at −195° to −183°C. Equilibrium functions, isoteric heats of adsorption, and integral molar entropy values were calculated. The data show a marked difference between the surface nature of the unreduced and of the reduced samples, but adsorption behaviour on the samples

reduced at various temperatures showed only slight variations.

### Solubility of Nickel in Molten Lead

E. PELZEL: 'The Solubility of Copper, Nickel and Cobalt in Molten Lead.'
*Metall*, 1955, vol. 9, Aug., pp. 692–4.

Following a condensed review of the literature of the binary systems of lead with copper, nickel and cobalt, and some consideration of the ternary copper-nickel-lead group, the author reports experimental determinations, the results of which are summarized in the table below:—

**Solubility of Copper, Nickel and Cobalt in Molten Lead**

| Temperature °C. | Cu % | Ni % | Co % |
|---|---|---|---|
| 324 (solidification temperature) .. | — | 0·107 | — |
| 325·5 (solidification temperature) .. | 0·11 | — | — |
| 327 (solidification temperature) .. | — | — | 0·037 |
| 370 .. .. .. | 0·146 | 0·153 | 0·041 |
| 450 .. .. .. | 0·280 | 0·264 | 0·050 |
| 500 .. .. .. | 0·370 | 0·386 | 0·053 |
| 540 .. .. .. | 0·554 | 0·465 | 0·057 |
| 635 .. .. .. | 1·080 | 0·850 | 0·089 |
| 727 .. .. .. | 2·300 | 1·425 | 0·137 |

It is noted that these determinations indicate the solubility of cobalt as lower than had previously been assumed.

### Self-Discharge of the Negative of Nickel-Alkaline Accumulators

P. HERSCH: 'Mechanisms of Self-Discharge of the Negative of Alkaline Accumulators.'
*Trans. Faraday Soc.*, 1955, vol. 51, Oct., pp. 1442–8.

It is known that the negative in nickel–alkaline accumulators loses charge on standing idle: in nickel-iron cells the loss is of the order of 20 per cent. per month, and in modern types of nickel-cadmium cell it is about 2–3 per cent. In contrast to the lead-acid battery, no attention has previously been given to the corrosive mechanism causing self-discharge in alkaline storage cells, which is the subject of the present paper. It is shown that in nickel-iron batteries self-discharge of the negative is caused mainly by anaerobic attack of the active material by water. This process can be retarded by cathodic protection. A cadmium negative component is practically immune from attack by water, but in an incompletely sealed battery local action occurs, due to reduction of oxygen at the three-phase boundary formed by supporting rods—electrolyte-atmosphere.

### Nickel-Oxide Electrodes for Alkaline Accumulators

G. W. D. BRIGGS, E. JONES and W. F. K. WYNNE-JONES: 'The Nickel-Oxide Electrode.' *Trans. Faraday Soc.*, 1955, vol. 51, Oct., pp. 1433–42.

Although nickel-alkaline cells have been in large-scale use for many years, and it has frequently been stated that changes in voltage occurring when such cells are charged and discharged are due in large measure to the behaviour of the positive plates, little information has been published with regard to the electrochemistry of the nickel-oxide system in alkaline solution. This lack of data is believed to be due in considerable measure to the difficulties involved in making nickel-oxide electrodes, which has resulted in the use, by different investigators, of various types of electrode, the majority of which have not been well suited for quantitative examination.

The present paper is a report of the first stage of a study of electrochemical behaviour of nickel-oxide electrodes in alkaline solution: it contains a description of methods developed for production of electrodes suitable for such experiments, and a preliminary report on their behaviour. Studies were made of three main methods to which attention had already been directed in the literature: (1) anodic attack of nickel, (2) chemical attack of nickel in NaClO, and (3) electrodeposition of nickel oxide. Method (1) gave no satisfactory results: method (3) produced electrodes which had only a low coulombic capacity, but otherwise fulfilled all requirements. Electrodes prepared by method (2) showed a coulombic capacity about ten times as great as that of the electrodeposited type, but were in other respects less satisfactory. In the experiments reported electrodes were prepared by methods (2) and (3): a detailed account is given of the procedures used. Polarization curves for both types of electrode, at constant current in potassium hydroxide solution, are discussed, and it is shown that, in suitable conditions, the coulombic efficiency of the electrode reaction may approach 100 per cent.

## ELECTRODEPOSITION AND OTHER COATING METHODS

### Effect of Chromium and Other Deposits on Fatigue Strength of Steel

J. E. STARECK, E. J. SEYB and A. C. TULUMELLO: 'The Effect of Different Chromium Deposits on the Fatigue Strength of Hardened Steel.' *Plating*, 1955, vol. 42, Nov., pp. 1395–402.

The aim of the work reported was to determine the effect of various types of chromium deposit on the fatigue limit of hardened low-alloy chromium-molybdenum steel (S.A.E. 4140). The tests were made in the R. R. Moore rotating-beam fatigue-testing machine, using specimens of reduced diameter. A nominal thickness of coating of 0·010 in. was chosen as standard, but some observations were made also on the influence of thickness (0·0006 to 0·010 in.). Correlation of the number of hairline cracks found in the deposits with the fatigue properties of the respective specimens indicated internal tensile stress as an important factor in fatigue, and comparison was therefore made between plated steel untreated after coating and specimens baked at various temperatures after plating.

Consideration of the fatigue properties of specimens obtained by plating from the various solutions on steel hardened to the 100-ton tensile level led to the development of an improved plating solution designed to give lower stress in the coating. This bath was of the following composition (g./L.) $CrO_3$ 600, $SO_4$ 4·8. It was operated at a temperature of 130°F. (54°C.), at a current density of 3 amp./sq. in.

The improvement, after baking at 550°F. (288°C.) in the fatigue strength of the steel plated from this bath was so considerable that further tests were made on the same steel heat-treated to a tensile strength of 120 tons per sq. in. The specimens were plated from the improved bath and were baked at 450°F. (230°C.) for four hours. The unplated steel showed a fatigue limit of 103,000 p.s.i. (46 tons per sq.in.), while the plated and baked specimens gave a value of 101,000 p.s.i. (45 tons per sq. in.), a reduction of less than 2 per cent.

The results revealed no correlation between variation in thickness of plating and fatigue strength. Recommendations are made with regard to temperature ranges (*a*) suitable for baking of steel plated with the respective types of chromium coating investigated, and (*b*) in relation to the nature of the steel plated.

Comparative tests, made on the same steel (at the 100-ton tensile level) plated with 0·001 in. of nickel, copper or lead, gave the following results:—

**Influence of Nickel, Copper and Lead Coatings on Fatigue Strength of Steel**

| Deposit | Fatigue Limit 1000 p.s.i. |
|---|---|
| Unplated Steel .. .. | 109 |
| Watts Nickel .. .. .. | 45·0 |
| Bright Nickel (Organic brightener) .. .. | 85·0 |
| Copper .. .. .. | 87·5 |
| Lead .. .. .. .. | 105 |

It is noted that the steel plated with Watts-type nickel gave a fatigue limit of only 45,000 p.s.i. (20 tons per sq. in.), whereas the bright-nickel-plated steel showed 85,000 p.s.i. (38 tons per sq. in.). The bright-nickel coating was shown to have a compressive stress (−3000 p.s.i.): the data thus agree with the findings of Almen that steel carrying compressively stressed bright nickel plating is characterized by better fatigue properties than steel plated with a Watts type of coating, which has an internal tensile stress.

**Deposition of Nickel by Chemical Reduction: Alcoplate Coatings**

W. J. CREHAN: 'Nickel Plating by Chemical Reduction.' *Product Finishing*, 1955, vol. 26, July, pp. 148–52.

This is a practical article on the use of the Kanigen process (based on developments by General American Transportation Company, and by American Locomotive Company, which latter Company designates this type of coating as Alcoplate). Typical physical properties of the plating are given, together with some data on its resistance to corrosion by common corrodents. A flow sheet illustrates the plant used at the A.L.C. works.

The importance of suitable surface preparation of the basis metal is emphasized; surface profiles resulting from blasting with four different abrasives are shown. The relative suitability of various basis metals for plating by chemical reduction is reviewed, and a note is added on some applications in which the process has already proved successful. The wide range of hardness obtainable in the coatings is illustrated by curves showing properties obtained on heating for one, six, or twelve hours at 25°–700°C. A caution is added with regard to conditions for which the chemically-reduced coatings are *not* recommended.

**A.S.M. Metals Handbook: Revised Sections**

See note on p. 2.

## NON-FERROUS ALLOYS

**Monel: Fifty Years of Development and Use**

W. A. MUDGE: 'Monel, 1905 to 1955.' *Metal Progress*, 1955, vol. 68, Oct., pp. 132–5.

A historical review, from the direct production, in 1905, of the natural alloy, by oxidation of nickel-copper matte, through the early days of development and the discovery of the wide range of applications for which the high-nickel nickel-copper alloy is suitable. The gradual build-up of the 'Monel family' of wrought and cast variants of the original composition is traced, and a survey is made of the present-day use of the alloys of this group in many of the most important branches of industry. Particular attention is directed to the importance of the extensive corrosion-test facilities which have been available for evaluating the Monel alloys: these have proved the suitability of such materials for application in widely varying service conditions involving exposure to corrosive atmospheres and liquids. It is emphasized, also, that the study of age-hardenable Monel alloys has made an important contribution to the development of other hardenable nickel-base materials.

Compositions and properties quoted as typical of the grades of Monel alloy now in commercial production are shown on page 9.

**Vacuum Metallurgy: Symposium**

See abstracts on pp. 2–5.

**Structure of Molybdenum-Nickel-Chromium Alloys**

C. BRINK and D. P. SHOEMAKER: 'A Variation on the σ Phase Structure: The Crystal Structure of the *P* phase, Mo-Ni-Cr.' *Acta Crystallographica*, 1955, vol. 8, Nov. 10, pp. 734–5.

For discussion of the *P* phase in ternary alloys of transition-group metals, the authors direct attention

**Properties of Monel Alloys**

| Trademark | Available Forms * | Chemical Composition (Maximum unless specified otherwise) | | | | | | | Yield†† | | Tensile | | Elongation % in 2" in. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Ni % | Cu % | Mn % | Fe % | Si % | S % | C % | 1000 p.s.i. | t.s.i.§ | 1000 p.s.i. | t.s.i.§ | |
| **Wrought Alloys** | | | | | | | | | | | | | |
| Monel .. .. | A, B, C, D, E, F | 63–70 | bal. | 2·0 | 2·5 | 0·50 | 0·024 | 0·30 | 25–165 | 11·0–73·5 | 70–170 | 31·25–76·0 | 50– 2 |
| 'R' Monel .. | A, B, C .. | 63–70 | bal. | 2·0 | 2·5 | 0·50 | 0·025–0·060 | 0·30 | 25–155 | 11·0–69·0 | 70–160 | 31·25–71·5 | 50– 2 |
| 'K' Monel† .. | A, B, C, D, E, F | 63–70 | bal. | 1·50 | 2·0 | 1·0 | 0·01 | 0·25 | 40–190 | 18·0 85·0 | 90–210 | 40·0–94·0 | 45– 2 |
| 'KR' Monel† .. | A, B, C .. | 63–70 | bal. | 1·50 | 2·0 | 1·0 | 0·01 | 0·20–0·30 | 40–180 | 18·0–80·5 | 90–200 | 40·0–89·5 | 45– 2 |
| '326' Monel .. | A, B, C, D, E .. | 55–60 | bal. | 2·25 | 2·5 | 0·75 | 0·024 | 0·30 | 25–155 | 11·0–69·0 | 75–160 | 33·5–71·5 | 50– 2 |
| **Cast Alloys** | | | | | | | | | | | | | |
| Monel .. | G .. .. | 62–68 | bal. | 0·5–1·5 | 2·5 | 1·0–2·24 | | 0·35 | 32–40 | 14·5–18·0 | 65–90 | 29·0–40·0 | 45–25 |
| 'H' Monel .. | G .. .. | 62–68 | bal. | 0·5–1·5 | 3·0 | 2·25–3·49 | | 0·30 | 70–90 | 31·25–40·0 | 90–115 | 40·0–51·5 | 3– 1 |
| 'S' Monel .. | G .. .. | 62–68 | bal. | 0·5–1·5 | 3·5 | 3·5–5·0 | | 0·25 | 80–115 | 35·5–51·5 | 110–145 | 49·0–64·5 | 4– 1 |

* A—Rods and bars; B—Forgings; C—Wire; D—Sheet; E—Strip; F—Tubing; G—Castings.
† Age-hardenable, with 2 to 4 per cent. aluminium and 0·25 to 1·0 per cent. titanium.
†† 0·2 per cent. offset. § To nearest ½ ton.

to *Journal of Metals*, 1951, vol. 3, Oct., pp. 872–6, and 1952, vol. 4, Oct., pp. 1071–5.

In the molybdenum-nickel-chromium system the *P* phase occupies, at 1200°C., a region in the ternary diagram in the neighbourhood of the atom ratio 42 : 40 : 18, between a ternary σ-phase region round 27 : 28 : 45, and a binary δ-phase region, Mo–Ni, with atom ratio close to 50 : 50.

### Nickel-Cadmium Alloys

F. LIHL and E. BUHL: 'The Alloys of Cadmium with Cobalt, Iron and Nickel.'
*Zeitsch. f. Metallkunde*, 1955, vol. 46, Nov., pp. 787–91.

Review of previous literature, supplemented by report of original experiments. It is pointed out that, in all three systems, the high melting point of the one component and the low melting point of the other introduce difficulties in preparation of alloys by normal melting and casting. The advantages of the amalgam method for preparation of such alloys are emphasized, with a note on the essential features of this procedure and reference to some examples for which the senior author has previously used it with success. An account is then given of its application to the preparation of alloys of the three series under consideration, with particular reference to procedure devised for production of the nickel-cadmium alloys.

Extensive details are given of the structure of the three series of alloys within the range 300°–400°C. It is observed that in the solid state cadmium is practically immiscible with cobalt and with iron. In the nickel-cadmium system three intermediate phases were found, γ at 18·5, γ′ at 29–29·5 and β at 47–48·5 at. per cent. nickel, respectively. X-ray examination revealed close similarity between the γ and the γ′ phases; they correspond, respectively, to the formulae $Cd_{21}Ni_5$ and $Cd_5Ni_2$. The β phase is of complex structure and its characteristics have not yet been fully investigated.

### Aluminium-Nickel Alloys: Constitutional Diagram

H. W. L. PHILLIPS: 'The Equilibrium Diagram of the System Aluminium-Nickel.' *Inst. Metals Annotated Equilibrium Diagrams No.* 18, Oct., 1955.

The diagram presented is based on a critical review of all available authoritative data. It has been taken almost entirely from the diagram published by ALEXANDER and VAUGHAN (*Jnl. Inst. Metals* 1937, vol. 61, p. 247), supplemented in certain aspects by the work of other investigators, to whose original work reference is given.

### Solubility of Nickel in Molten Lead

See abstract on p. 7.

### Magnetic Viscosity in Nickel Precipitation-Hardening Alloys

See abstract on p. 11.

### Production of Nickel-Germanium Alloys by Electrolysis of Fused Salts

M.-J. BARBIER-ANDRIEUX: 'Preparation of Alloys of Germanium with Nickel, Iron and Manganese by Electrolysis of Fused Compounds.'
*Comptes Rendus de l'Académie des Sciences*, 1955, vol. 241, July 18, pp. 309–11.

Further to work on the production of germanium by electrolysis of fused compounds (*ibid.*, 1955, vol. 240, p. 2104), the method has been extended to the preparation of binary alloys of germanium with nickel, iron, or manganese. Brief details are given of the baths used and of the phases present in the electrodeposited alloys. This preliminary work indicates the possibility of using such procedure for production of an extensive series of germanium alloys.

### Nickel-containing Aluminium Alloys: B.S. Specifications

BRIT. STANDARDS INSTN.: 'Aluminium and Aluminium Alloy Ingots and Castings for General Engineering Purposes.' *B.S.* 1490: 1955. Price 10/-.

This Standard specifies requirements for aluminium ingots and aluminium-alloy ingots and castings in twenty-two alloys, in various conditions. Section I contains general clauses applicable to ingots; Section II includes general clauses applicable to castings, and Section III covers composition and properties of individual types of ingots and castings. Appendix A contains details of tensile test pieces mentioned in the body of the specification and Appendix B comprises a summary table of approximate metric equivalents (for use in calculating properties), and the numbers of related British aircraft specifications. At the beginning of the schedule a useful reference table of compositions of the materials is given.

### Properties of Gold-Nickel Alloys

J. SIVERTSEN and C. WERT: 'Young's Modulus of Gold-Nickel Alloys.'
*Bull. Amer. Physical Soc.*, 1955, vol. 30, Nov. 25, p. 29.
Abstract of paper presented at 1955 Meeting of the American Physical Society, Chicago, November, 1955.

At high temperatures alloys of gold and nickel form solid solutions over the whole range, but at low temperatures, over most of the composition range, the stable alloy is a mixture of a gold-rich phase and a nickel-rich phase. By quenching an alloy from the high-temperature region to room temperature the solid solution characteristics may be retained, but quenched alloys of intermediate composition, when annealed at slightly elevated temperatures, decompose into a two-phase material. Changes in some of the physical properties (e.g., electrical resistance) and in structure have been found to accompany this phase separation, and alteration of internal friction has also been observed during annealing, although the latter change precedes the phase separation as observed by other means. In connexion with the change in internal friction, measurements were made, by the authors, of changes in Young's modulus occurring during the annealing of a binary alloy containing 30 per cent. of nickel. No increase in the modulus was associated with the changes in internal friction.

### Nickel Alloys in De-Icing Equipment

See abstract on p. 17.

### High-Pressure, High-Temperature Processing of Powders: Vitron Process

See abstract on p. 5.

## NICKEL-IRON ALLOYS

### Nickel and Nickel Alloys in the Electrical Industries

P. R. BARDELL: 'Magnetic Materials in the Electrical Industry. Published by *McDonald and Co. (Publishers), Ltd., London*, 1955; 288 pp. Price £1 12s. 6d.

The aim of this book is concisely stated in its preface: it is intended primarily for senior students in physics and electrical engineering, and for physicists and engineers in industry. It seeks to bridge the gap between an academic study of the properties of magnetic materials and the too limited treatment of the subject which is possible in most textbooks for engineers. Essentially, the aim is to link the properties of materials with their applications.

The early chapters of the book are concerned with the theoretical aspect of magnetism (a section which is most usefully amplified by a glossary of relevant terms and units and by a note explaining magnetic terminology).

Following this introduction, the next three chapters deal, respectively, with the history and development of permanent magnets, soft magnetic materials, and methods of test used for evaluation of properties.

Industrial applications of the alloys falling into the respective categories are then reviewed, *viz.*:—power-frequency and communication-frequency applications, magnetic recording, magnetic amplifiers, and transducers.

The arrangement of the book is such as to provide easy reference, and there are detailed indexes to subject matter and to the names of the writers whose work is referred to in the text.

### High-Frequency Technique for Study of Structural Transformations in Nickel-Iron Alloys

F. FRAUNBERGER: 'A High-Frequency Technique for Metallurgical Investigations on Magnetic Alloys.'
*Zeitsch. f. Metallkunde*, 1955, vol. 46, Oct., pp. 749–51.

This paper describes a method for determination of constitutional changes in metals and alloys by measurement of high-frequency resistance. Examples of the application of the method relate to the (1) formation of $Fe_3O_4$ on the surface of a steel wire, as influencing the skin effect, and (2) the inter-relation of the gamma-epsilon transformation in cobalt and the temperature-dependence of the high-frequency permeability of the metal.

*See also—*

K. STIERSTADT: 'Lattice Transformations in Irreversible Iron-Nickel Alloys', *ibid.*, pp. 751-5.

Binary alloys containing 3-25 per cent. of nickel were studied by the method referred to in the previous abstract. The observations made confirm existing data on the course of the transformations involved and the temperatures at which they occur. An additional irreversibility phenomenon found by the present author (designated Type 2 irreversibility) is believed to be associated with relaxation of the stressed alpha lattice.

**Ferromagnetic Domains in Nickel-Alloy Permanent-Magnet Materials**

L. F. BATES: 'Ferromagnetic Domains in Permanent-Magnet Materials.'
*Research*, 1955, vol. 8, Dec., pp. 462-72.

The article is based on a lecture delivered to the Permanent Magnet Association in April 1955. An account is given of the domain concept of ferromagnetism, and of its applications to various types of ferromagnetic material.

Quantitative tests of the validity of contemporary theories, made by means of Bitter powder-pattern technique, are described, with examples of powder patterns which are of particular interest in interpreting magnetic processes occurring in metals. Special attention is given to powder patterns developed on the surface of Alnico (nickel-aluminium-cobalt-iron alloy), and columnar Alcomax (Columax), a niobium-containing nickel - aluminium - cobalt - copper - iron alloy in which special directional magnetic effects are induced.

**Effect of Pulsed Magnetic Fields on Magnetization Reversal in Permalloy Tape**

D. S. RODBELL and C. P. BEAN: 'Influence of Pulsed Magnetic Fields on the Reversal of Magnetization in Square-Loop Metallic Tapes.'
*Jnl. Applied Physics*, 1955, vol. 26, Nov., pp. 1318-23.

Change in the state of magnetization of a ferromagnetic metal is associated with generation of eddy currents of appreciable magnitude, and in many cases the magnetic fields from these currents determine the geometry of the domain walls, the motion of which gives rise to the changing magnetization. Conversely, the amount and distribution of the eddy currents is determined by the geometry of the domain walls and their motion. For materials thicker than several thousandths of an inch, the eddy currents account for the major part of the energy loss during rapid magnetization.

In this paper reversal of magnetization in square-loop tapes of 65 per cent. nickel Permalloy is described in terms of the domain geometry, and the dependence of this geometry upon the wave shape of the applied magnetic field. For a steady field the amplitude of which is slightly greater than the coercive force, the reversal is accomplished by a growth of a single axial domain originating at the thin tape edge. For steady fields of much greater amplitude, the reversal domain grows in from all tape surfaces.

**Magnetic Viscosity in Nickel Precipitation-Hardening Alloys**

J. H. PHILLIPS, J. C. WOOLLEY and R. STREET: 'The Influence of Temperature on Magnetic Viscosity.'
*Proc. Physical Soc., Sect. B.*, 1955, vol. 68, June 1, pp. 345-52.

The paper reports measurements made to determine the effect of temperature on irreversible magnetic viscosity in the following types of precipitation-hardening alloy:—platinum-cobalt (50-50 at. per cent.), nickel-gold (75-25 at. per cent.), and nickel-aluminium-iron-base alloy of the Alnico type.

In connexion with the measurements on Alnico, it is noted that previous relevant investigations of this material have been made on specimens having relatively high coercivity, corresponding to an appreciable development of the precipitated phase, whereas the results given in this paper were obtained on an Alnico specimen in which precipitation was in a much earlier stage of development.

The results obtained in these experiments are interpreted in terms of Néel's disperse-field theory of magnetization, with the additional assumption that strains set up between coherent precipitate and matrix are responsible for production of the disperse fields.

**Shape and Crystal Anisotropy of Permanent-Magnet Alloy**

E. A. NESBITT and H. J. WILLIAMS: 'Shape and Crystal Anisotropy of Alnico 5.'
*Jnl. Applied Physics*, 1955, vol. 26, Oct., pp. 1217-21.

In 1952 Heidenreich and Nesbitt demonstrated that Alnico 5 is composed of fine particles having dimensions of the order of $10^{-6}$ cm. Electron micrographs of crystals heat-treated in a magnetic field along the [001] direction showed that the precipitate grew in the direction of the field applied during heat-treatment, but not at right angles to it. Optimum permanent-magnet properties were associated with a spacing of about 200 Å between the plates of the precipitated phase, and the plates themselves were found to be made up of rows of rods, such rods being approximately 75-100 Å in diameter, and 400Å long. These measurements were confirmed by later investigators.

More recently it was shown that orientation of fine precipitated particles could be detected by measuring the magnetic torque on single crystals at various field strengths, and in addition it was found that the separate effects of shape and crystal anisotropy, on coercive force, could be determined. This earlier work was done on $Fe_2NiAl$: the present paper reports similar experiments on Alnico 5. It is concluded that the high coercive force of single crystals of Alnico 5 depends upon the shape and anisotropy of the fine precipitated plates, and that the crystal anisotropy of the plates is negligible. Data available up to the present indicate that the alloy consists of plates of precipitate of high magnetic saturation, separated by a matrix of comparatively low magnetic saturation. The plates are made up of rods of precipitate, but they act magnetically like single-domain plates.

## CONSTRUCTIONAL STEELS

### Isothermal Characteristics of Carburized Nickel-Molybdenum Steel

G. MAYER and R. H. HICKLEY: 'The Isothermal Transformation Characteristics of Carburized 2% Nickel-Molybdenum Steel.'
*Metallurgia*, 1955, vol. 52, Nov., pp. 236–9.

Atlases of isothermal-transformation diagrams now available cover many types of plain and alloy steel currently used in Britain, America and Germany, but the data contained in them relate mainly to direct-hardening steels, and the literature contains relatively little information on the characteristics of carburized steels. Data for such steels are, however, a practical need, particularly as a source of information on treatments which should be employed for martempering and isothermal annealing. For such purposes it is desirable to have a series of diagrams representing both the variation in carbon content from the core through the carburized case, and the effect of various heat-treatments used in commercial practice.

This technical note presents diagrams portraying the isothermal-transformation characteristics of a carburized nickel-molybdenum steel to B.S. En 34 specification. The steels studied covered a range of carbon contents representative of the core and of four positions in the case of the carburized steel. The majority of the results correspond to the hardening stage of the double-quenching treatment (final oil-quenching from 770°C.), which is often used for carburized components, but for the core steel and for a 0·84 per cent. carbon steel, diagrams representative of single-quench treatments, (*a*) from 840°C., and (*b*) from the carburizing temperature (915°C.), are also included. [The 2 per cent. nickel-molybdenum steel was selected for study in this connexion because it is widely used in industry. Carburized steels of this type can be heat-treated in a variety of ways to produce consistently good mechanical properties in the core (typical values are given in the paper), and the tendency to grain-boundary carbide formation in the case is lessened by the presence of nickel.]

In all the steels except the 0·84 per cent. carbon type, isothermal transformation was followed by the microscopic method, using tape samples 0·03 in. thick. For the high-carbon steel the dilatometric method was employed, on specimens machined from 9 s.w.g. wire: the extent of reaction after apparent completion of transformation, or after 24 hours (whichever was the shorter time) was microscopically determined. $M_S$ temperatures were found by the Greninger and Troiano technique, and the critical temperatures were determined dilatometrically, on heating the steels at a rate of 100°C. per hour. Hardness was measured on specimens quenched into water after completion of isothermal transformation, or after the 24-hour treatment.

The series of diagrams given show that increase in carbon content from the core through the case results in:

(*a*) greater stability of the under-cooled austenite and, therefore, longer incubation periods in both the pearlite and bainite ranges;

(*b*) earlier completion of isothermal reaction in the pearlite range; and

(*c*) later completion of isothermal reaction in the bainite range.

### Banding in Nickel-Alloy Steels

C. F. JAYCZAK, D. J. GIRARDI and E. S. ROWLAND: 'On Banding in Steel.'
*Trans. Amer. Soc. Metals* 1955, vol. 48, *Preprint* 20; 33 pp.

Banded structures in steels arise from carbon segregation into preferred regions, and the numerous investigations which have been made on the phenomenon of banding have led to general agreement that its primary cause is the effect of alloy segregation on the location of carbon. Other factors influence the degree, type and form of banding, either *per se* or by their influence on the degree of chemical segregation: among such factors are the temperature and time of austenitizing, the diffusion rates of carbon and of the alloys present, grain-size, cooling rates, and rates of nucleation and growth of decomposition products of austenite.

The studies reported in this paper were made on five steels, see table below.

Banding characteristics were established by studying the behaviour of the steels in transforming—

(1) to ferrite and pearlite,

(2) to martensite on direct quenching, and

**Composition of Steels Investigated**

| A.I.S.I. Type | C % | Si % | Mn % | Cr % | Ni % | Mo % |
|---|---|---|---|---|---|---|
| 1340 | 0·39 | 0·27 | 1·70 | 0·16 | 0·29 | 0·03 |
| 2340 | 0·41 | 0·29 | 0·68 | 0·23 | 3·20 | — |
| 4140 | 0·39 | 0·31 | 0·82 | 0·96 | 0·13 | 0·20 |
| 4340 | 0·42 | 0·29 | 0·72 | 0·82 | 1·74 | 0·25 |
| 5140 | 0·42 | 0·27 | 0·85 | 0·81 | — | — |

(3) to martensite on quenching after a prior isothermal treatment at the upper nose of the TTT curve.

Reasons for selecting these aspects for study are given.

The observations made confirm that the primary cause of banding in rolled steel products is chemical heterogeneity. The effects of other nucleating agents, such as banded inclusions, etc., are believed to be either minor or non-existent.

In the steels studied, it was found that carbide-forming elements, e.g., chromium or molybdenum, tend to increase the carbon concentration in their vicinity, whereas solution-type elements, such as nickel, have the reverse effect. Thermal treatment of the steels showed that those alloyed primarily with carbide-forming elements homogenize more rapidly than those containing primarily solution-type elements. Comparison of the mechanical properties of the S.A.E. 4340 nickel-chromium-molybdenum steel in the banded condition and after treatment for 100 hours at 2200°F. (1205°C.) showed that only transverse ductility was improved by such treatment, and that the degree of improvement was not sufficient to be commercially significant.

### Static-Fatigue Phenomena in High-Strength Nickel-Alloy Steels

R. H. RARING and J. A. RINEBOLT: 'Static Fatigue of High-Strength Steel.'
*Trans. Amer. Soc. Metals*, 1955, vol. 48, *Preprint* 31; 12 pp.

Brittle fracture of high-tensile steels after long periods under static load has recently assumed increasing interest in connexion with the use, in fabricated structures, of steels heat-treated to levels above the conventional maximum of about 180,000 p.s.i. (80 tons per sq. in.). In some cases failures have developed under stresses well below the yield strength of the steel, in stress cycles below those generally associated with cyclic fatigue failures, and the surface markings characteristic of cyclic fatigue have not been found. The phenomenon is therefore frequently called 'static fatigue'.

A recent analysis of static-fatigue failures of plated high-strength steels suggested that hydrogen embrittlement might be a contributory cause, and since hydrogen may be introduced into steel during various operations (e.g., in melting), production methods, as well as plating, called for study.

The work reported in this paper is one phase of an investigation sponsored by the Wright Air Development Center, at the U.S. Naval Research Laboratory, Washington, D.C. It deals with various factors which are known to influence hydrogen content, paying special attention to melting conditions, and to cadmium plating. The material used was low-alloy nickel-chromium-molybdenum steel to S.A.E. 4340 specification.

Heats of this steel were melted (1) in air, (2) in vacuum, and (3) in argon, and the resulting materials were heat-treated to tensile strengths of 230,000 and 280,000 p.s.i. (102·5 and 125 tons per sq. in.). Tests were made on these steels in the unplated condition, and on parallel specimens carrying a coating of cadmium.

Resistance to static-fatigue failure was determined by applying loads for extended periods to notched tensile specimens. The results show that the properties of steels at high tensile-strength levels, as determined by conventional short-time tests, are not necessarily a reliable criterion of their behaviour in service. The possibility of static-fatigue failure in such steels must be recognized when a choice is being made of composition and treatment of high-strength steels for engineering structures.

Susceptibility, to static fatigue, of unplated low-alloy nickel-chromium-molybdenum steel at the 230,000 p.s.i. (102·5 tons per sq. in.) level, was negligible, but at the 280,000 p.s.i. (125 tons per sq. in.) level static fatigue failures occurred at loads as low as 83 per cent. of the short-time breaking strength.

It is concluded that melting in vacuum or in an argon atmosphere has no significant effect on resistance to static fatigue. Cadmium plating lowered the breaking strength and greatly increased susceptibility to static-fatigue failure.

### Influence of Silicon in Nickel-Alloy Steels

C. H. SHIH, B. L. AVERBACH, and M. COHEN: 'Some Effects of Silicon on Mechanical Properties of High-Strength Steels.'
*Trans. Amer. Soc. Metals*, 1955, vol. 48, *Preprint No.* 9; 33 pp.

Attention is directed to recent papers reporting that the addition of silicon to hardenable steels retards softening on tempering, and mention is made of some applications in which the stiffening effect of silicon is utilized, e.g., in springs.

In the experimental work reported in this paper, four steels were used, see table below:—

| | C % | Si % | Mn % | S % | P % | Ni % | Cr % | Mo % |
|---|---|---|---|---|---|---|---|---|
| 4340* .. .. | 0·39 | 0·31 | 0·75 | 0·012 | 0·007 | 1·66 | 0·75 | 0·24 |
| 4340 (1·5 Si) .. | 0·37 | 1·45 | 0·76 | 0·019 | 0·010 | 1·95 | 0·84 | 0·24 |
| 4325 .. .. | 0·26 | 0·23 | 0·63 | 0·020 | 0·010 | 1·91 | 0·77 | 0·26 |
| 4325 (1·5 Si) .. | 0·26 | 1·42 | 0·76 | 0·018 | 0·009 | 1·95 | 0·60 | 0·25 |

* Commercial heat. The other steels are laboratory induction heats.

All the steels were normalized at 1600°F. (870°C.) prior to machining. The tensile properties were measured on 0·252-in. diameter test bars, and for impact tests standard V-notch Charpy specimens were employed. Special precautions were taken to minimize the effects of surface condition on impact properties.

The higher-carbon steels were austenitized for 30 minutes in a lead bath at 1525°F. (825°C.) and the lower-carbon types were treated at 1550°F. (840°C.). All specimens were oil-quenched at 75°±5°F. (23·8°±2°C.). Tempering was done in oil, salt or lead baths, according to the temperature used.

Hardness and tensile properties are summarized for each of the steels as a function of tempering temperatures up to 1200° or 1300°F. (650° or 705°C.): duration of tempering was one hour in each case. The curves show that softening on tempering is retarded by silicon, and it appears possible to obtain in the silicon steels somewhat higher strengths without corresponding loss in ductility or in impact strength. At high strength levels the elastic limit of the silicon-containing steels is approximately half the engineering yield strength. Silicon additions have no influence on the maximum elastic limit. A warning is given that although addition of silicon has several beneficial effects at the higher strength levels, impact properties may be impaired by tempering at relatively high temperatures (temper embrittlement).

End-quench hardenability tests were made, and data on retained austenite are presented as a function of rate of cooling from the hardening temperature. It is shown that substantial amounts of retained austenite may be developed by retarded cooling.

Measurements of elastic limit by the repeated-load method and of endurance limit by rotating-beam tests indicate that the two properties may be related.

### Weld Cracking in High-Strength Nickel-Alloy Steels

R. P. SOPHER, A. J. JACOBS and P. J. RIEPPEL: 'Investigation of Weld-Metal Cracking in High-Strength Steel.' *Welding Jnl.*, 1955, vol. 34, Nov., pp. 544S-52S. Report of research sponsored by the U.S. Air Materiel Command.

Preliminary survey of the relevant literature from 1935 onwards, supplemented by consultation with representatives of industry, led to the following major conclusions:—

(1) the major type of cracking in weld metals is hot cracking,

(2) most cracking in weld metals is intergranular and appears to be associated with segregation of low-melting or brittle constituents, as well as with stresses imposed during cooling,

(3) hot cracking in ferritic weld deposits is promoted by elements such as sulphur, phosphorus, oxygen, nickel (+sulphur) and carbon, but is reduced by manganese.

The experimental programme was drawn up in the light of the above findings. Three types of parent steel were used: (1) S.A.E. 43XX, of the following approximate composition: nickel 2, chromium 1, molybdenum 0·25, per cent., with varying carbon and sulphur, (2) nickel-chromium-molybdenum-vanadium steel corresponding to A.W.S./A.S.T.M. E15016 grade, (3) boron-containing 'lean-alloy' nickel - chromium - molybdenum steel to A.I.S.I. 86B40. Tensile properties were determined at various temperatures, while cooling from the molten condition.

Correlation of these data with composition of the steels and with sensitivity to hot cracking indicates that increasing carbon, sulphur and phosphorus contents are adverse: sulphur and phosphorus appear to be more detrimental than carbon. It is believed that high-carbon filler wires having a low-residual content of sulphur and phosphorus could safely be used to deposit under conditions of high restraint, and that such weld metal could be heat-treated with the parent material to high strength levels. An explanation of the hot-cracking phenomenon is suggested in terms of typical hot-strength and ductility curves: the views advanced are supported by the results of cracking tests.

### Nickel Steel for Low-Temperature Service: Specification

AMER. SOC. TESTING MATERIALS: 'Forged or Rolled Carbon and Alloy Steel Flanges, Forged Fittings and Valves and Parts for Low-Temperature Service.' *A.S.T.M. Designation* A. 350-55. *A.S.T.M. Standard*, 1955, *Part* 1, *Ferrous Metals*, pp. 314-19.

The specification covers parts made from steel to the requirements shown below and on page 15.

Test conditions are specified in detail, with particular reference to temperatures at which the impact tests are made, −50°F. (−45°C.) for grade LF-1 and −150°F. (−100°C.) for grade LF-3, and with regard to conditions to be observed in impact testing.

**Chemical Composition**

| | C % | Si % | Mn % | S % | P % | Ni % |
|---|---|---|---|---|---|---|
| Grade LF-1 | 0·30 max. | — | 1·06 max. | 0·050 max. | 0·040 max. | — |
| Grade LF-3 | 0·20 max. | 0·15–0·35 | 0·30–0·60 | 0·040 max. | 0·040 max. | 3·25–3·75 |

**Tensile Properties at Room Temperature**

| | U.T.S. | | Y.P. | | Elongn. in 2 in. % min. | Redn. of Area % min. |
|---|---|---|---|---|---|---|
| | p.s.i. min. | t.s.i. min. | p.s.i. min. | t.s.i. min. | | |
| Grade LF–1 | 60,000 | 27 | 30,000 | 13·5 | 25 | 38 |
| Grade LF–3 | 70,000 | 31·25 | 40,000 | 18·0 | 25 | 50 |

It is noted that as the austenitic nickel-chromium steels covered by A.S.T.M. Designation A. 182 for Flanges, Fittings, Valves, etc., for High-Temperature Service exhibit no significant loss of Charpy impact strength at temperatures as low as −325°F. (−198°C.) they are being used for low-temperature service without the necessity for conducting impact tests, and are therefore not included in specification A.350–55.

### Non-Magnetic High-Alloy Steels

W. GRASS: 'Development and Present Position of Non-Magnetic Steels.'
*Stahl und Eisen*, 1955, vol. 75, Nov. 17, pp. 1558–62.

This is essentially a review article. Structures associated with the non-magnetic condition are discussed in connexion with the influence of nickel, manganese, and carbon, and with the use of chromium in conjunction with high-nickel and/or manganese.

The inter-relation of magnetic properties and structure indicates the following groups as coming into consideration for non-magnetic materials: (1) manganese steels, (2) manganese-chromium steels, (3) nickel steels, (4) nickel-chromium steels, (5) manganese-nickel steels, (6) manganese-nickel-chromium steels.

In all these types small percentages of other elements may be present, and selection from among these groups is determined by the end-use of the material, cost, and other considerations.

The author gives tables showing the composition of the non-magnetic steels covered by D.I.N. specification 17 006, and lists typical steels used in other countries. The physical and mechanical properties of the German standard grades are detailed and discussed. Consideration is given to the mechanical working of non-magnetic steels, (in relation to retention of the austenitic structure which is requisite for maintenance of non-magnetic quality), and reference is made to test methods used for assessment of magnetic characteristics. Brief consideration is given to the workability of the non-magnetic steels.

## HEAT- AND CORROSION-RESISTING MATERIALS

### Heat-Resisting Alloys: 25 Years' Progress

V. N. KRIVOBOK and E. N. SKINNER: 'Stainless and Heat-Resistant Alloys.'
*Metal Progress*, 1955, vol. 68, Sept., pp. 118–22.

A review of progress during the past 25 years. Methods used for evaluation of properties of heat-resisting materials are briefly considered, with special reference to the importance of the time factor and to the limited utility of standard tensile tests as a basis for assessing long-term properties.

Materials which have been developed in the period under review are considered in three groups: iron-, nickel-, and cobalt-base alloys. Compositions and creep-rupture strengths (at 1200° and 1500°F: 650° and 815°C.) are shown for typical alloys of the respective groups.

Attention is also directed to complications which arise due to high-temperature corrosion attack, e.g., oxidation, corrosion by vanadium pentoxide, corrosion by sulphur and by sodium compounds, and by other substances arising from the use of fuel oils. In conclusion, some suggestions are made as to further research which is urgently required as a means of improving high-temperature materials, to meet increasingly exacting demands. Among the subjects considered worthy of study are fundamental phenomena associated with age-hardening (e.g., in nickel-base alloys), the rôle of boron, the influence of trace elements, and the effects of molybdenum, cobalt, tungsten and vanadium on strength and ductility of the matrix of high-temperature alloys. Further work is also called for with regard to the effects of heat-treatment, grain-size, order-disorder structures, and lattice imperfections.

### High-Temperature Materials for Power Plants

A. LEVY: 'High-Temperature Power Plant Materials: Application of High-Temperature Materials to Aircraft Power Plants in the Temperature Range of 1200°–1400°F.'
*Aircraft Engineering*, 1955, vol. 27, September, pp. 292–8.

It is emphasized that the materials which can be considered for service in the range 1200°–1400°F. (650°–760°C.) are limited to alloys based on iron and/or nickel and/or cobalt. The contribution of each of the individual elements used in these high-temperature alloys is discussed, and the broad composition and short-time mechanical properties of typical alloys of iron-, nickel-, and cobalt-base are reviewed.

Considerations involved in selecting a material for high-temperature applications are then reviewed in relation to mechanical and physical properties required at service temperatures, critical alloy content, fabrication characteristics, scaling-resistance, and cost. Stress-rupture, creep, thermal-expansion, thermal-conductivity and elastic-modulus data are

tabulated for typical alloys of the respective series under consideration, and some comparisons are made of the surface-emission characteristics of high-temperature alloys and other materials, in various surface conditions. Factors limiting elevated-temperature performance of metallic materials are considered, with special reference to strength and melting point.

The above survey of properties and of basic considerations governing service at high temperatures is followed by a discussion of the materials used in components of afterburners, ram jets and rockets, where the primary requirement is for short-time service at very high temperatures.

Conditions obtaining in the respective applications are described, with illustrations of the respective parts.

Critical evaluation of the properties of currently known heat-resisting materials, and of the conditions involved in the most advanced types of power plant, leads to the conclusion that the limit of constructional metal performance is rapidly being approached. Operation of a ram-jet engine having hot spots at 2200°-2300°F. (1205°-1260°C.) represents working conditions within 200°-300°F. (110°-165°C.) of the melting temperatures of the best high-temperature alloys. Designers must therefore look forward to the use of molybdenum, ceramic coatings, or cermets to meet the requirements which will arise as a result of increasing temperatures of combustion.

### Creep-Rupture Properties of Cold-Worked Austenitic Steels

N. J. GRANT, A. G. BUCKLIN and W. ROWLAND: 'Creep–Rupture Properties of Cold-Worked Type 347 Stainless Steel.'
*Trans. Amer. Soc. Metals*, 1955, vol. 48, *Preprint* 2; 14 pp.

Benefits obtainable by cold- or warm-working are recognized in connexion with both the low-temperature and the high-temperature properties of metals and alloys, and for certain types of heat-resisting alloy warm working is a standard operation. The advantages of cold- or warm-working have not, however, yet been fully explored in relation to the austenitic stainless steels. The present paper makes a contribution to this aspect, in the form of an investigation of the effect of cold working on the high-temperature properties of niobium-stabilized austenitic steel. The steel used was of the following composition:—carbon 0·057, chromium 18·28, nickel 9·42, silicon 0·65, manganese 1·36, niobium 0·58, nitrogen 0·040, per cent., balance iron. Bar stock ($\frac{5}{8}$ in.) was hot-forged to $\frac{1}{2}$-in. rounds, which were solution-treated for one hour at 2000°F. (1095°C.) and water-quenched. Sections were cold-swaged to give reductions of area of 10·0, 20·8, 30·4, 37·6, 58·0 and 81·2, per cent.

In recrystallization experiments the specimens were held for periods of 0·5-50 hours (or in some cases for 500 hours) at temperatures in the range 1200°-1700°F. (650°-925°C.). The observations made on minimum recrystallization temperature, as a function of cold working and of duration of annealing, indicate that for a severely cold-worked condition recrystallization in 50 hours does not occur below about 1325°F. (715°C.) and that even 500 hours should not produce recrystallization at 1300°F. (705°C.).

Mechanical tests at room temperature show that both yield and tensile strengths rise with increasing degree of cold working, and that such increase is still proceeding rapidly after 30 per cent. cold working. Elongation decreased sharply with rise in tensile strength, but reduction of area changed but little throughout.

Ferrite was not detected until more than 30 per cent. reduction of area by cold work had been achieved: after 80 per cent. cold work ferrite was present in amounts varying between 20 and 25 per cent.: the ferrite content was higher in the centre of the specimens than at the surface. Beyond about 40 per cent. cold work hardness increased very little.

From a review of creep-rupture data for various test times at temperatures of 1200°, 1300° and 1500°F. (650°, 705° and 815°C.), the authors draw the following conclusions:—

A useful degree of strength in creep rupture at high temperatures can be produced by cold work (or warm work) as follows:—

(*a*) At 1200°F. (650°C.) up to 30 per cent. cold reduction yields improvement up to at least 1,000 hours.

(*b*) At 1300°F. (705°C.) up to 10 per cent. cold reduction improves a 1,000-hour life and over 30 per cent. is beneficial for a one-hour life or less.

(*c*) At 1500°F. (815°C.) up to 20 per cent. cold reduction improves properties for a one-hour life, but cold work should be avoided for rupture lives of greater than about one hour. (The solution-treated condition is best.)

(*d*) At 1100°F. (595°C.) and below, it appears that very significant improvements can be achieved for long-time use by cold work up to 30 per cent. or more.

### Vacuum Metallurgy: Symposium

See abstract on p. 2.

### Nickel-containing Materials in Nuclear Power Plant

See abstract on p. 5.

### Titanium-Carbide Cermets with Nickel and Nickel-Alloy Binders

F. P. KNUDSEN, R. E. MORELAND and R. F. GELLER: 'Physical Characteristics of Titanium-Carbide-Type Cermets at Elevated Temperatures.'
*Jnl. Amer. Ceramic Soc.*, 1955, vol. 38, Sept. 1, pp. 312-23.

This paper comprises a report of work carried out at the National Bureau of Standards, under the sponsorship of the Wright Air Development Center. The materials examined were, in all cases, of titanium-carbide base, and contained varying amounts of

nickel, cobalt or nickel-alloy binder. Nominal composition, and calculated and determined densities of the specimens, are recorded.

The examination, of selected compositions, included *bending tests* (at 1500°, 1650°, 1800°, 1900° and 2000°F. (815°, 898°, 982°, 1038° and 1093°C.), *tensile creep tests*, at various stresses, at temperatures of 1200°, 1500°, 1600° and 1800°F. (648°, 815°, 870° and 982°C.), *determinations of linear thermal expansion* (data not yet complete), and *metallographic examination* of typical specimens in various conditions. Results are recorded in detail.

The bending tests indicated that the strength of the cermets decreased linearly, by about 20–30 per cent., as the content of nickel binder increased from 5 to 30 per cent. Ductility showed a marked improvement as the nickel content was raised beyond 20 per cent.

The tensile creep tests, made on a limited number of specimens containing 20, 25 and 30 per cent. of nickel, on a cermet containing 30 per cent. of a nickel-alloy binder, and on a specimen containing 50 per cent. of nickel, showed the nickel-alloy-bound material to be the most creep-resistant of all the materials tested.

Metallographic examination of the tensile specimens revealed that, with one exception, no noticeable change in microstructure took place during creep test. In the individual case, a nickel-alloy-bound cermet stressed for 1073 hours at 1850°F. (1010°C.), it was found that the carbide grains had coalesced during test.

### High-Pressure, High-Temperature Processing of Powders: Vitron Process

See abstract on p. 5.

### Rapid-Heating Tests on Inconel

G. J. HEIMERL and J. E. INGE: 'Tensile Properties of Some Sheet Materials under Rapid-Heating Conditions.' *Nat. Advisory Committee for Aeronautics, Research Memorandum* L55E12b, June 9, 1955; 10 pp.

Whereas in conventional stress-strain tests the temperature is held constant, in the rapid-temperature test the load is held constant and the material is heated at a constant rate of temperature increase, until failure occurs. This report gives results of tests in which sheet specimens of various aluminium alloys, Inconel, and a titanium alloy were tested at temperature rates of 0·2°–100°F. per second, under constant load conditions. Yield and rupture temperatures obtained under such conditions are compared with tensile properties of the same materials exposed under constant temperature for ½ hour.

Results to date indicate that in general, yield and rupture temperatures increase logarithmically with temperature rates below 100°F. per second, except where effects such as ageing alter the results. Under rapid-heating conditions materials may sometimes be stronger than is indicated by conventional tensile ½-hour exposure data, but the relative strength varies with the temperature rate and the nature of the material tested. No theory is yet available to explain the complex transient behaviour of materials under rapid-heating conditions.

### Machining of Nimonic 90 Rotors for Gas Turbines

'Multispindle Profiling of Integral-Blade Rotors.' *Aircraft Production*, 1955, vol. 17, Dec., pp. 482–91.

All models of Blackburn-Turboméca gas turbines are based essentially on the original Palas 600 design developed by Société Turboméca, Bordes, Basses-Pyrenées, France. Various modifications have been introduced, in order to meet the demands of the British market, and the result is the 500–600 range of turbines designed to meet power requirements between 250 and 500 b.h.p. The main components of the turbines are a single-stage centrifugal compressor, driven by a single-stage axial turbine, with an annular-type combustion chamber arranged between them. The impeller is made from a light alloy, and the rotating guide vanes from nickel-chromium stainless steel, while the turbine rotor, which is the subject of this article, is of Nimonic 90, nickel-chromium-cobalt-base alloy. For the nozzles and combustion chamber the nickel-chromium-base alloy Nimonic 75 is used.

This article describes, with detailed illustrations, the methods used by Blackburn and General Aircraft, Ltd., for machining the Nimonic 90 rotors, and it is particularly emphasized that it has been possible to ensure simplicity and efficient operation by using standard machine tools modified for special-purpose use.

### Machining Thin Sections of Austenitic Stainless Steels

'Machining Thin Sections. Simultaneous Double-Sided Copy-Turning of Gas-Turbine Compressor Rotors.' *Aircraft Production*, 1955, vol. 17, Dec., pp. 472–6.

Apart from the difficulties normally encountered in machining discs of large diameter, thin-section rotors, such as are used in gas turbines, present a number of special problems. Gradual build-up of vibration, by resonance, and deformation of the part by spinning-over of the material, are matters of particular concern. For example, single-sided profiling on section thicknesses of less than 0·15 in., at a diameter of 12 in., may lead to distortion resulting from unbalanced tool-point pressure, and the single-side method has the further disadvantage of necessitating double setting, with possibility of eccentricity between the two sides and production of an unbalanced part.

These and other difficulties have been overcome at the works of Rolls-Royce, Ltd., by adoption of a balanced-cut double-sided turning technique, by which the tools are traversed simultaneously across the two surfaces. In this article a detailed description is given of the equipment and methods used, as applying to the fabrication of stainless-steel compressor rotors.

### Nickel Alloys in De-Icing Equipment

'De-Icing Elements. Manufacture and Application of Electrothermal De-Icing Elements to Aircraft Components.'
*Aircraft Production*, 1955, vol. 17, Dec., pp. 506–10.

As a result of the progressively increasing performance expected from modern aircraft, with consequently greater emphasis on aerodynamic cleanness, much attention is being given to de-icing systems which are flush with the surface of the aircraft components to which they are applied. Typical of the areas in which accretion of ice has a deleterious effect on airflow, and can lead to loss of control or severe reduction in operational efficiency, are the leading edge of a wing, fairings at the entry of engine air-intakes, airscrew-spinners and intake ducts.

This article describes one of the systems which have been developed to provide efficient de-icing without disturbance of airflow: it is designed and constructed by Dunlop Rubber Company, Ltd., and is applicable to the majority of aircraft components requiring this form of protection. The de-icer consists of a metal element embedded between layers of rubber, the lowest of which is attached to the surface of the aircraft part which it is to protect. The heater-mat element, which is cropped in zig-zag form from a flat sheet of material, is of Brightray (nickel-chromium alloy, specific resistance 110 microhms/cm. cube), Ferry (nickel-copper alloy, specific resistance 49 microhms/cm. cube), nickel (specific resistance 9 microhms/cm. cube), and phosphor bronze (specific resistance 12 microhms/cm. cube). Elements made from these materials are prepared in short strips and are joined in series to form a complete circuit. The arrangement of the respective types, to provide for the variations in heat intensity required at the various points on the surface, is illustrated in this article by reference to the geometry of the heater elements applied to the Rolls-Royce intake duct of the Dart engine which powers the Vickers-Viscount airliner. Fabrication of the individual components of the heaters, and details of assembly, finishing and inspection are given, with illustrations of the various operations involved.

### Nickel-Alloy Steel Castings for High-Pressure, High-Temperature Service

AMER. SOC. TESTING MATERIALS: 'Alloy Steel Castings for Pressure-containing Parts Suitable for High-Temperature Service.'
*A.S.T.M. Designation* A. 217-55.
*A.S.T.M. Standards*, 1955, *Part* 1, *Ferrous Metals*, pp. 183-9.

One type of carbon-molybdenum, four grades of chromium-molybdenum, and two grades of nickel-chromium-molybdenum steel are covered. Nickel-containing types are shown in the table below.

The specification embodies requirements for annealing, normalizing and tempering treatments, and provides for compulsory tensile and hydrostatic tests. By mutual agreement between manufacturer and purchaser, magnetic-particle, radiographic, and destructive forms of tests may be carried out to verify the quality of the castings.

### Steel Nuts for High-Temperature, High-Pressure Service

AMER. SOC. TESTING MATERIALS: 'Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service.'
*A.S.T.M. Designation* A. 194-55T.
*A.S.T.M. Standards*, 1955, Part 1, *Ferrous Metals*, pp. 126–30.

Ten grades of material are specified, for service in conditions varying in severity. Among the types recommended for service under the most severe conditions are 12 per cent. chromium steel, unstabilized 18–8 chromium-nickel steel (A.I.S.I. Type 304), niobium-stabilized chromium-nickel steel (A.I.S.I. Type 347), titanium-stabilized chromium-nickel steel (A.I.S.I. Type 321), and free-machining 18–8 containing 0·18–0·35 per cent. of sulphur or 0·15–0·35 per cent. of selenium (A.I.S.I. Type 303).

Requirements laid down in the specification include methods of fabrication, stress-relief treatment for nuts made by cold working, hardness testing, and drift and stripping tests for nuts of specified grades.

(The specification corresponds to A.S.M.E. Boiler and Pressure Vessel Code Specification SA-914, and is endorsed also by the Manufacturers' Standardization Society of the Valve and Fittings Industry.)

### Corrosion-Resistant Alloy Castings: Specification

AMER. SOC. TESTING MATERIALS: 'Corrosion-Resistant Iron-Chromium and Iron-Chromium-Nickel Alloy Castings for General Application.'
*A.S.T.M. Designation* A. 296-55.
*A.S.T.M. Standards*, 1955, Part 1, *Ferrous Metals*, pp. 1053-7.

These standards are, in effect, a revision and consolidation of the following specifications, *which they replace:*—

20% Chromium, 9% Nickel Alloy-Steel Castings (A. 198-39).
Chromium Alloy-Steel Castings (A. 221-39).
Chromium-Nickel Alloy-Steel Castings (A.222-39).
Nickel-Chromium Alloy-Steel Castings (A.223-39).

| Designation | C % | Si % | Mn % | S % | P % | Ni % | Cr % | Mo % |
|---|---|---|---|---|---|---|---|---|
| WC–4 | 0·20 max. | 0·60 max. | 0·50–0·80 | 0·06 max. | 0·05 max. | 0·70–1·10 | 0·50–0·80 | 0·45–0·65 |
| WC–5 | 0·20 max. | 0·60 max. | 0·40–0·70 | 0·06 max. | 0·05 max. | 0·60–1·00 | 0·50–0·90 | 0·90–1·20 |

The new combined specification covers *nine grades of iron-chromium-nickel alloy:*—

CF-8, CG-12, CF-20, CF-8M, CF-8C, CF-16F, CH-20, CK-20, CE-30, and

*three grades of iron-chromium alloy:*—

CA-15, CB-30 and CC-50.

In most cases the designations and compositions correspond to those shown in the 1954 list of standard casting alloys issued by The Alloy Casting Institute. These materials represent types of alloy castings suitable for broad ranges of application involving service in corrosive conditions.

In addition to composition, heat-treatments for the respective alloys are specified, and tensile and hardness properties are specified. Provision is also made for non-destructive testing, if agreed between manufacturer and purchaser.

**Heat-Resistant Alloy Castings: Specification**

AMER. SOC. TESTING MATERIALS: 'Heat-Resistant Iron-Chromium and Iron-Chromium-Nickel Alloy Castings for General Applications.'
*A.S.T.M. Designation* A. 297-55.
*A.S.T.M. Standards*, 1955, *Part* 1, *Ferrous Metals*, pp. 1058-61.

This composite specification also is a revision and consolidation of individual earlier schedules, *which it replaces*, viz.:—

20% Chromium, 9% Nickel Alloy-Steel Castings (A.19-39).
Chromium-Alloy Steel Castings (A.221-39).
Chromium-Nickel Alloy-Steel Castings (A.222-39).
Nickel-Chromium Alloy-Steel Castings (A.223-39).

The new specification covers nine grades of austenitic chromium-nickel alloys:—

HF, HH, HI, HK, HE, HT, HU, HW, HX,

and one high-chromium alloy, HC.

Composition limits and tensile requirements are specified.

In this case also the designations of the respective grades are in accordance with Alloy Casting Institute nomenclature. As with the corrosion-resistant castings, the materials included in the composite schedule are types suitable for general application at elevated temperatures. For details of castings intended for use under more specialized conditions, attention is directed to appropriate schedules in the A.S.T.M. Standards.

**Stainless-Steel Billets and Bars for Re-Forging**

AMER. SOC. TESTING MATERIALS: 'Corrosion-Resisting Steel Billets and Bars for Re-Forging.'
*A.S.T.M. Designation* A. 314-55.
*A.S.T.M. Standards*, 1955, Part 1, *Ferrous Metals*, pp. 842-4.

The specification covers 14 grades of austenitic nickel-chromium steel, 14 grades of high-chromium steel, and two 4-6 per cent. chromium steels of varying carbon content. Provision is made for ladle and check analysis, and for a macroscopic etching test for determination of soundness.

**Corrosion-Resisting Steel Wire: Specification**

AMER. SOC. TESTING MATERIALS: 'Chromium-Nickel Corrosion-Resisting Steel Spring Wire.'
*A.S.T.M. Designation* A. 313-55.
*A.S.T.M. Standards*, 1955, Part 1, *Ferrous Metals*, pp. 984-6.

The specification covers a grade of round wire intended primarily for use in springs which will operate at temperatures up to 350°F. (175°C.) without noticeable loss of physical properties, and in which up to 600°F. (315°C.) the properties are sufficiently well retained to make the wire suitable for many applications, such as thermostat, stove and hot-oil valve springs. The steel, which may be made by the electric-furnace process and is cold-drawn to tensile requirements which are laid down for wire of 0·009-0·036 in. diameter, is of the following composition: carbon 0·15 max., silicon 1·00 max., manganese 2·00 max., sulphur 0·03 max., phosphorus 0·04 max., chromium 18·00-20·00, nickel 8·00-9·50, per cent. A coiling test is specified, dimensional tolerances are laid down, and provision is made for ensuring satisfactory surface condition.

**Austenitic Stainless-Steel Wire Strand: Specification**

AMER. SOC. TESTING MATERIALS: 'Stainless-Steel Wire Strand.'
*A.S.T.M. Designation* A. 368-55.
*A.S.T.M. Standards* 1955, Part 1, *Ferrous Metals*, pp. 1093-5.

This schedule relates to strand suitable for use as guy wires, overhead ground wires, etc. The material used is chromium-nickel steel to A.I.S.I. specifications 301 (chromium 16-18, nickel 6-8, per cent.) or 302 (chromium 17-19, nickel 8-10, per cent.). Minimum breaking-strength requirements are laid down for medium- and high-strength grades of strand, of various nominal diameters and containing varying numbers of wires in the strand.

**Copper-Sulphate Test for Determining Susceptibility to Intergranular Corrosion**

AMER. SOC. TESTING MATERIALS: 'Tentative Recommended Practice for Conducting Acidified Copper-Sulphate Test for Intergranular Attack in Austenitic Stainless Steel.'
*A.S.T.M. Designation* A. 393-55T.
*A.S.T.M. Standards*, 1955, Part 1, *Ferrous Metals*, pp. 1135-8.

The procedure recommended is suitable for testing wrought products (including tubes), castings, and weld metal, of austenitic stainless steel. Details of equipment and procedure relate to:—

The test container, specimen holders, and heating media.

The test solution (made by dissolving 100 g. of $CuSO_4 . 5H_2O$ in 700 ml. of distilled water, adding 100 ml. of $H_2SO_4$ (sp. gr. 1·84), and making up to 1000 ml. with water).

Test specimens (shape and size, surface finish, and sensitizing treatment).

Test conditions (volume of solution, number of specimens per flask, and boiling period).

Bend test, and method of evaluating the behaviour of the specimen under test.

**A.S.M. Metals Handbook: Revised Sections**

See note on p. 2.

**Rare-Earth Additions to Stainless Steel**

C. S. Du MONT, J. E. GATES and C. M. HENDERSON: 'An Approach to the Study of the Effect of Rare-Earth Additions to Steel by Use of Radioactive Tracer Techniques.'

*Trans. Amer. Soc. Metals*, 1955, vol. 48, *Preprint* 18; 16 pp.

One aspect of co-operative investigation by Battelle Memorial Institute and an industrial firm, on poor hot-forgeability in steels, has been concerned with the microstructure of the steels and the influence of harmful segregation of intermetallic compounds or non-metallic inclusions.

Radioactive trace elements are being used to delineate the location and distribution of impurities which might not be revealed by conventional metallographic examination, and this paper describes the first study by this technique.

Radioactive Mischmetall of the following composition was used: cerium 44, lanthanum 29, neodymium 17, praseodymium 7, gadolinium 1, magnesium 2, iron 0·1, per cent. An account is given of the methods used to make the Mischmetall radioactive. Since previous laboratory work had shown that additions of Mischmetall to a 25-20 nickel-chromium steel containing copper and molybdenum consistently improved hot-working properties (as measured by the hot-forge cone test), the work reported in this paper was done on the same material.

The results indicated that the additions of radioactive Mischmetall were uniformly distributed throughout the matrix of the steel. There was indication of slight concentration of radioactivity in the interdendritic zones of as-cast material, but there was no evidence of any concentration of these atoms at the grain boundaries, or within the non-metallic inclusions present. Heat-treatment at forging temperatures had the effect of homogenizing these interdendritic concentrations of the radioactive constituents.

It is intended that future work shall cover the study of the effect of Mischmetall on austenitic steels containing radioactive forms of elements which are known to have a harmful effect on hot-working properties.

**Stress-Corrosion Cracking in Hardenable Stainless Steels**

P.LILLYS and A. E. NEHRENBERG: 'Effect of Tempering Temperature on Stress-Corrosion Cracking and Hydrogen Embrittlement of Martensitic Stainless Steels.'

*Trans. Amer. Soc. Metals*, 1955, vol. 48, *Preprint* 30; 27 pp.

This paper is relevant to the growing interest in stress-corrosion cracking of corrosion-resisting steels, referred to by BLOOM: see abstract in *Nickel Bulletin*, 1955, vol. 28, No. 11, p. 198.

Study of four high-chromium steels (two of which were of the 2 per cent. nickel type) indicates that for those which have been heat-treated to high levels of hardness, tempering at about 500°F. (260°C.) affords minimum susceptibility to cracking by hydrogen embrittlement.

Maximum susceptibility to stress-corrosion cracking and hydrogen embrittlement results from tempering in the range 800°-1000°F. (425°-540°C.).

The presence of delta ferrite minimizes the tendency to stress-corrosion cracking, by narrowing the range of tempering temperatures which produce susceptibility, and by interfering with crack propagation.

**Ductility of Stainless Steel: Influence of Rate of Strain and Temperature**

G. W. FORM and W. M. BALDWIN: 'The Influence of Strain Rate and Temperature on the Ductility of Austenitic Stainless Steel.'

*Trans. Amer. Soc. Metals*, 1955, vol. 48, *Preprint* 4; 14 pp.

Investigations already made to elucidate changes in the ductility in austenitic steels brought about by variation in rates of strain and temperature have not fully resolved certain observed discrepancies.

In the work reported in this paper tensile tests were made at various rates of strain (from 0·01 in./in./min. up to 19,000 in./in./min.), and over a range of temperatures from −321° to +750°F. (−196° to +400°C.). These tests were supplemented by magnetic measurements and by microhardness tests on broken test specimens, in order to determine to what extent the $\gamma \rightarrow \alpha$ transformation might be involved in the sensitivity of austenitic steels to strain rate. The steels used were of the following composition:—

| Type | C % | Si % | Mn % | S % | P % | Cr % | Ni % | Fe % |
|---|---|---|---|---|---|---|---|---|
| A.I.S.I. 303* .. | 0·045 | 0·54 | 1·37 | 0·30 | 0·016 | 17·49 | 10·30 | bal. |
| A.I.S.I. 310 .. | 0·044 | 0·35 | 1·82 | 0·006 | 0·023 | 22·72 | 19·72 | bal. |

* Free-machining steel.

The tensile specimens were machined from fully annealed rod.

The results lead to the conclusion that most, if not all, of the peculiarities in the ductility characteristics of austenitic steels must be explained on some basis other than the $\gamma \rightarrow \alpha$ transformation. The principal evidence supporting this conclusion is as follows:

(*a*) Both the steels showed similar ductility *vs.* temperature and strain-rate curves, although the 25-20 chromium-nickel steel shows no $\gamma \rightarrow \alpha$ transformation at any temperature or any rate of strain.

(*b*) Even in the 18-8 steel no $\gamma \rightarrow \alpha$ transformation is found above room temperature, at which point ductility drops with increasing strain rate.

(*c*) Where the $\gamma \rightarrow \alpha$ transformation is found in the 18-8 steel (at room temperature and below) it occurs in amounts bearing no direct relationship with ductility behaviour. At constant rates of strain, fall in temperature increases the amount of $\alpha$ phase formed, but results in decreased ductility: at constant test temperature an increase in rate of strain results in both a fall in ductility and a lessening of the amount of $\alpha$-phase formed.

### Nickel-containing Alloy for Ink Tubing in Fountain Pens

'Sampling Works for the Snorkel.'
*Steel*, 1955, vol. 137, Oct. 17, p. 135.

Difficulty has been experienced by the Sheaffer Pen Company in finding the most suitable material for the retractable filler tube of their fountain pens. In the first versions of the pens embodying this feature the 'snorkel' tube was made in 14-ct. gold, a material which gave the necessary resistance to corrosion by ink, but was somewhat expensive, and too easily bent. A cheaper, stiffer, and more uniform material has now been developed, in which the necessarily close dimensions, superior surface finish and other essential features are easily obtained. The material selected, which is designated L-607, is a high-nickel, high-cobalt alloy.

### Nickel-Molybdenum Alloys: Corronel B

HENRY WIGGIN AND CO., LTD.: 'Corronel B: Properties and Applications.' *Publn. No.* 975*, 1955; 8 pp.

Following the announcement, in 1929, of nickel-molybdenum-base alloys having outstanding resistance to hydrochloric acid, considerable research has been carried out to determine optimum compositions and the full scope of the corrosion-resisting properties of the alloys. In the United Kingdom industrial experience to date has been based mainly on nickel-molybdenum-iron alloys in cast form, but during the past few years wrought forms have been developed, and the nickel-molybdenum-iron alloy Corronel B is now available in the usual mill forms.

This publication gives data on its physical and mechanical properties, resistance to corrosion by hydrochloric, phosphoric and sulphuric acids, working processes suitable for the alloy, and welding technique.

Study of nickel-molybdenum-base compositions has shown that, in general, corrosion-resistance improves with increasing molybdenum content. Addition of up to 10 per cent. of iron at the 30 per cent. molybdenum level has no significant influence on rates of corrosion, but further additions cause marked deterioration in this respect. The alloy which has been found to be the most practicable, combining maximum corrosion-resistance with the necessary degree of workability, contains about 66 per cent. of nickel with 28 per cent. of molybdenum, and 6 per cent. of iron.

* *We shall be pleased to supply a free copy of this publication.*

### Protection of Offshore Equipment by Monel

C. J. FRITTS: 'Corrosion Control on Offshore Drilling and Producing Equipment.'
*Corrosion*, 1955, vol. 11, Nov., pp. 471t-6t.

In connexion with oil production, offshore operations present problems in protecting installations located in water of greater depth than is normally involved in the construction of piers and other stationary marine equipment. Almost all platforms and floating equipment are of steel, and are therefore subject to corrosion, and there is currently an urgent need for adaptation of known methods of protection to the specific conditions existing in such equipment. The author reviews development and the present position, with particular reference to conditions existing in the Gulf of Mexico, and tests in progress in that area.

In the case of stationary platforms three zones of varying corrosiveness exist:—(1) the atmospheric zone, where the steel is subject to corrosion by high humidity and some degree of salt spray, (2) the splash zone near the water line, where the steel is in contact with spray and is alternately wet and dry, and (3) the submerged zone, where the steel is continually wetted by salt water. Of these, the splash zone is the most critical, and it is towards protection in this area that most of the work is now directed.

In the atmospheric zone (10 ft. or more above the water line) a 6-coat vinyl system has been found to give excellent results. It consists of a wash primer, a zinc-chromate primer, three 'build' coats, and one top coat, and is applied in a minimum thickness of 6 mils. Approximately fifty different coating systems are currently under test in the Gulf, but the exposures have not yet been sufficiently long for full evaluation to be made.

In the splash zone various methods of protection may be used, but all are relatively expensive, and choice must be made with due regard to the service which will be required from the equipment. The author gives a critical review of methods which may be adopted, with their relative costs. In this connexion reference is made to the use of Gunite, Monel, porcelain enamel, sheet Neoprene, flame-sprayed polyethylene, plastic tapes over vinyl, metallizing with zinc or aluminium, vinyl mastic systems, and protective jackets.

With regard to Monel, the following comments are made:—

> 'Several platforms were jacketed in the splash zone, during construction, with 16-gauge 'B' Monel. This Monel is formed into cylindrical jackets, which are slipped over the platform members and welded at the top and bottom to form a watertight seal. If properly applied, the Monel can withstand severe blows without tearing. Monel jacketing probably is the best known method of protecting the splash zone if a platform is to be at the same location for a number of years. It would not be economical to use Monel on a platform which would be moved to another location of different water depth in a short time, although the cost of Monel would be well justified for a platform used for drilling in a proved field.'

For protection of submerged-zone areas on fixed and floating surfaces, cathodic protection is recommended. Use of magnesium anodes described.

**Monel: Fifty Years of Development and Use**

See abstract on p. 8.

**Inert-Gas Metal-Arc Welding of Stainless Steel**

C. L. RAILTON: 'Inert-Gas Metal-Arc Process Applied to the Welding of Stainless Steel.'
*Welding*, 1955, vol. 23, Dec., pp. 455-64.

The author describes experiments on the welding of 18-8 chromium-nickel stainless steel to B.S. En 58B specification, in thicknesses of 14 s.w.g. to $\frac{1}{2}$-in., in sheet and plate form. The electrodes used were layer-wound wire to specification 18-8-1, niobium-bearing: diameters were 0·035, 0·045 and 0·0625 in. Argon was employed as the protective medium. Equipment, arrangement of torch, control apparatus, etc., are described and illustrated.

Quality of welds was based on evaluation of porosity, which is reported in terms of the number of pores per inch and mean pore diameter. The various stages of the tests and the main conclusions reached are summarized below:—

*Effects of Additions of Oxygen to the Inert Shielding Gas*

Penetration increased with the increasing amount of added oxygen, up to 3 per cent.: at 5 per cent. a slight drop was observed. The amount of penetration was slightly greater in beads on plate than in those on joints. It is concluded that if maximum penetration is desired, 3 per cent. of oxygen in the argon is desirable. The effect of oxygen is most marked in welding at speeds beyond those of manual operation: its influence on arc stability and penetration is illustrated by figures of welds made with argon only and with additions of 1, 3 or 5, per cent. of oxygen.

*Effect of Electrode Feed Rate and Arc Voltage*

Decrease in electrode feed rate gives increase in arc voltage, and in most cases results in continuous decrease in the amount of porosity in the welds. Penetration is reduced by increasing the arc voltage. For general work, conditions giving a quiet stable arc and low porosity should be chosen.

*Effect of Distance between End of the Contact Tube and the Work*

This variable was found to have a marked effect on the characteristics of the arc, and the author urges that it is one which should be noted when recording welding conditions.

*Speed of Welding*

This is largely dependant on the value of the welding current. Resulting from trials with various combinations of current and electrode size, recommendations are made with regard to settings suitable for making butt and fillet welds; the results of the various experiments on which these data are based are critically discussed, with many illustrations of results obtained in various conditions.

Mechanical tests on all-weld-metal specimens demonstrated clearly the desirability of interpass cleaning when making multi-run welds.

**Welding of 17-7 Chromium-Nickel Stainless Steel**

T. A. DICKINSON: 'Simple Procedures for Fusion Welding 17-7 Stainless Steel.'
*Sheet Metal Industries*, 1955, vol. 32, Oct., pp. 764-5.

Welding of stainless steel of the high-tensile 17-7 type, which is now being developed extensively for structural applications, has presented problems not encountered in welding the conventional 18-8 types. These have, however, been largely overcome, and in this article details are given of methods which have been found satisfactory in welding 17-7 steel for aircraft. The recommendations made are based on the experience of Northrop Aircraft, Inc., Hawthorne, California.

Cleaning and jigging of materials may be done in the same way as for 18-8 steels.

Use of a Linde H.W. No. 4 or No. 10 torch, with No. 8 ceramic cup and $\frac{1}{16}$-in., 2 per cent. thoriated tungsten electrode is recommended. A flow of argon or helium should be maintained through the torch, regulated in accordance with the thickness of the materials being welded: for 0·040-in. stock a flow of 12 cu. ft. per hour is suitable. A flow of argon or helium, again regulated by the thickness of the stock, should be maintained through the back-up bar. For 0·040-in. material 1-2 cu. ft. per hour for each 6-ft. of joint length has proved satisfactory.

Machine setting should be as low as possible consistent with production of 100 per cent. penetration. When welding 0·040-in. work with straight polarity d.c., this requirement necessitates the use of 25 volts, and 25 amps. A relatively high welding speed is advisable, with 0·040-in. stock at least 3 in. per minute.

The filler rod should be of 17-7 steel. It is preferable to use no flux, since it confers no advantage, and the presence of the flux creates a difficult cleaning problem.

Particular emphasis is laid on the importance of welding speed, since, if a reasonable standard of quality is to be maintained, 17-7 steel cannot be welded as slowly as other types of stainless steel. Because progress from beginning to end of each weld must be steady, it is essential that workers

using manual torches be specially competent. Tensile tests have shown that welds in 17-7 steel made according to the procedures detailed above will consistently withstand stresses of a magnitude similar to those for which the parent metal is suitable.

### Lithium Additions to Alloys for Brazing Stainless Steels

N. BREDZS and D. CANONICO: 'Lithium Additions to Brazing Alloys.'
*Welding Jnl.*, 1955, vol. 34, Nov., pp. 535S-43S.

In the introduction to this paper the authors point out that, in spite of considerable progress recently made in brazing fluxes, and in the use of reducing atmospheres, it is not yet possible in some cases to ensure completely satisfactory results. In particular, the brazing of stainless steel still calls for further improvement. When brazing these materials with fluxes the removal of the fluxing compounds, especially from large articles, may present difficulties. The comparative viscosity of fluxes saturated with metal oxides may inhibit penetration of the filler metal into joints having small clearances, and in such cases the joints are of poor uniformity and strength. In a reducing atmosphere, at practical brazing temperatures, stainless steel is subject to heavy oxidation if the atmosphere contains even the smallest amount of water vapour, and brazing without flux is therefore usually confined to small articles which can be protected from oxidation by very dry hydrogen having a dew point of −40°F. (−40°C.) or below. From these facts it is obvious that development of self-fluxing brazing alloys containing constituents capable of reducing base-metal oxides would represent substantial progress.

In considering addition elements which could have the desired effect, three major requirements have to be satisfied: (1) the elements must have high affinity for oxygen at the practical brazing temperatures; (2) the oxides of the deoxidizing metal should have comparatively low melting points or at least be capable of forming, with the oxides of the base metal, low-melting fusible slags; (3) for the manufacture of the self-fluxing brazing alloys, some solubility of the deoxidizing metal in the molten brazing alloy is essential. In addition, from the manufacturer's point of view, it is important to have a deoxidizing metal with a high boiling point, and finally, it is an advantage that additions of the deoxidizing metal shall reduce the surface tension of the molten brazing alloy, since this will promote wetting of the solid base metal.

The conditions posited above indicated the likelihood that metals of group I-A of the Periodic System (lithium, sodium, potassium, rubidium, caesium) would be likely to satisfy requirements. The chemical and physical properties of these elements, and of their oxides, are summarized in the paper, and the data demonstrate that only lithium has a high enough affinity for oxygen to be able to reduce most of the metallic oxides. Further, of the alkali metals, only lithium has a sufficiently high boiling point for effective manufacture of self-fluxing brazing alloys. One property of this metal is not favourable, i.e., the melting point of its oxide is high, about 1700°C., but since lithium oxide forms low-melting point slags with most of the metallic oxides, it was obvious that this would be a practically ideal metal for the purpose under consideration.

Study of the binary phase diagrams silver-lithium and copper-lithium indicated that lithium can be easily dissolved in both cases, and a study of the two types of alloy was therefore undertaken.

The first test covered investigation of the wetting of slightly oxidized carbon steel by molten silver containing 1 per cent. addition of the following deoxidizing elements: beryllium, magnesium, aluminium, silicon, calcium, nickel, copper, zinc, cadmium, tin, barium and lithium. The results showed the outstanding suitability of the silver-lithium alloys. Tests were then made with the same series of alloys, on a nickel-chromium austenitic steel, and again only the silver-lithium alloy proved thoroughly satisfactory. In order to investigate the practical applicability of the lithium-bearing silver alloys in brazing various carbon and stainless steels, tests were made with three types of brazing alloy (1) silver 99, lithium 1, per cent.; (2) silver 98, lithium 2, per cent.; (3) silver 71, copper 28, lithium 1, per cent. In this case the corrosion-resistance of the alloys was also determined, using air and water as the corrodents. The 99-1 and the 71-28-1 per cent. alloys showed entirely satisfactory corrosion-resistance: the 98-2 alloy was not so resistant nor so ductile as the other two. Nickel-chromium stainless steel strips, torch-brazed in oxy-acetylene atmosphere, using the 99-1 silver-lithium brazing alloy, gave sound, strong, joints, and satisfactory results were also obtained in an oxy-acetylene atmosphere on the same type of stainless-steel strip brazed with 99-1 copper-lithium alloy.

### Cracking in Austenitic Steel Weld Deposits

J. HEUSCHKEL: 'Initial Characteristics of Chromium-Nickel Steel Weld Metals.'
*Welding Jnl.*, 1955, vol. 34, Oct., pp. 484S-504S.

In the research reported in this paper short-time tensile tests on weld metals were made at temperatures from −300° to +2200°F. (−185° to +1205°C.), and were used as a means of studying the phenomenon of hot-crack sensitivity in austenitic and austenitic-ferritic welds. The results of these tests were supplemented by structural examination, hardness tests, and Magnegage determination of ferrite contents.

The range of weld compositions used was chosen to be representative of five types of austenitic steel:—

(1) 25-20 chromium-nickel steel of normal and high silicon content, and a 33-17 nickel-chromium steel.
(In these cases the structure was fully austenitic at room temperature.)

(2) 20-10 and 25-14 chromium-nickel steels.
(Structure containing 9 per cent. ferrite at room temperature.)

(3) 27-9 chromium-nickel steel.
(Structure containing 27 per cent. ferrite at room temperature.)

(4) Alloyed chromium-nickel steels,
(*a*) 18-8 type stabilized with titanium,
(*b*) 20-12 type containing 2 per cent. molybdenum.
(Structures containing, respectively, 6·5 and 7·5 per cent. of ferrite at room temperature.)

(5) A group of steels broadly of the 20 per cent. chromium, 9-11 per cent. nickel type, and containing varying amounts of niobium and other modifying elements.
(In these steels the ferrite content at room temperature varied from 0·2 to 19 per cent.)

In the tensile tests made at the various temperatures, ductility of a low order was observed in the region of 1800°F. (980°C.) in all compositions known to be susceptible to hot cracking, indicating that such cracking does not necessarily occur only at the moment of freezing.

The author concludes that welds may be ductile or brittle at high temperatures, irrespective of their room-temperature ferrite content. He further urges that, contrary to general belief, there is no single specific relation between as-deposited room-temperature ferrite content and hot ductility. It is concluded that welds which are fully austenitic at room temperature cannot, however, be ductile at high temperatures unless the grain boundaries are microscopically clean. Precise definitions of cleanliness in terms of micro-constituents are not yet possible, but the general influence of composition and purity is illustrated by reference to deposited metal of the A.I.S.I. 3000 austenitic nickel-chromium steel group.

The brittleness observed in the region of 1800°F. (980°C.) is shown to be related to the strength of the matrix at that temperature: the matrices of higher strength impose greater stresses on the grain and sub-grain boundaries and barriers and upon local particles, and, unless these are sufficiently strong at the high temperatures, failure may occur under low amounts of strain. Hot brittleness is therefore a function of the components which strengthen the matrix of the steel, as well as of those which weaken the grain or sub-grain boundaries. In commercial chromium-nickel steel weld metals, nickel and niobium provide the major sources of high-temperature strength in the matrix, while additions of chromium tend to lower the strength. Grain-boundary weakening is shown to be related to the presence of oxides, nitrides, carbides and silicates at the boundaries of the grains, sub-grains and particles, even when the sulphur and phosphorus contents are low.

For a given strength level, better high-temperature ductility is ensured by using alloying additions of manganese, titanium, molybdenum and tungsten with lowered nickel contents. A similar effect is secured by niobium, but this element is so effective a strengthener that under rapid quenching conditions welds containing it tend to become over-strong, and lacking in ductility at temperatures above 1500°F. (815°C.). Solution heat-treatment is effective in improving high-temperature ductility of niobium-bearing welds, but to achieve this improvement the weld has to be heated through the region of minimum ductility, and with complex or rigid parts cracking may occur during such transition unless special precautions are taken.

It is urged that in drawing up specifications every effort should be made to provide welds having adequate high-temperature ductility. This can be furthered by holding the silicon, carbon, nitrogen and oxygen to suitable minimum values, and by avoiding excessive additions of nickel and niobium. It is also important to avoid too high a chromium content, in order to prevent formation of brittle sigma phase. Specific limits will depend on individual conditions of operation.

The outlook for production of improved electrodes is considered to be promising: in particular, reference is made to the likelihood that good results may be used with compositions including manganese 4, molybdenum 0·90, per cent. With regard to evaluation of electrodes, it is urged that, while present practice is to assess them by the properties of the deposit at room temperature, a more suitable method would be to evaluate on the basis of performance within the 1500°-2200°F. (815°-1205°C.) range.

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## PATENTS

### Nickel Starting Sheets for Use in Electrolytic Refining

Easily divisible metal plates, to be used as starting sheets in electrolytic refining, are produced by applying to both sides of the sheet one or more lines of resist across the sheet, so that the width of the line is $W=\frac{2T}{3} \pm \frac{T}{10}$, where T is the thickness of the sheet, and then depositing metal onto both sides. The starting plate and the electrodeposited metal are preferably both nickel. The resist may be of non-conducting ink, lacquer, paint, wax or insulating tape.

MOND NICKEL CO., LTD. *Brit. Pat.* 740,581.

### Production of Nickel Powder of 'Cotton-Wool' Structure

Nickel or iron powder of 'cotton-wool' structure, which does not show undue shrinkage when sintered for the production of porous bodies, is made by decomposition of the appropriate carbonyl in a hot free space, diluting the carbonyl vapour with carbon monoxide or another gas, and with a very small amount of a nuclei-forming agent, preferably oxygen.

MOND NICKEL CO., LTD. (inventors, D. M. LLEWELLYN, A. B. SIMPSON and WEST, DEW. H.).
*Brit. Pat.* 741,978.

### Chemical Polishing of Nickel and Nickel Alloys

An earlier patent referring to the polishing of metal surfaces in solutions containing nitric and phosphoric acids, with or without acetic acid, drew attention to the limited amounts of water which could be tolerated

if good results were to be obtained. *U.S. Pat.* 2,446,060.

The present patent covers more dilute solutions, containing only phosphoric and nitric acid: the range of composition is phosphoric acid 5–83, nitric acid 2–50, water 15–45, per cent. A further feature of such solutions is that they retain their useful operation over a much longer period than baths of a more concentrated type.

In certain cases it may be necessary to prevent excessive foaming when the solutions are used at higher temperatures, and this is done by addition of alkali metal or ammonium ions, for example, sodium or potassium nitrate, phosphate, or sulphate. In polishing certain high-nickel alloys additions of sulphuric acid may be useful: typical baths are described for the chemical polishing of brass, nickel silver, and nickel.

MODERN ELECTROLYTIC PATENTS AND PROCESSES, LTD. (inventors, H. E. ZENTLER GORDON and R. H. PINNER). *Brit. Pat.* 738,744.

### Electrodes for Nickel–Alkaline Accumulators

Skeletons for use in forming positive electrodes for alkaline accumulators are produced by impregnating the pores of a porous non-metallic body (preferably graphite) with metals or alloys which resist electrochemical attack (preferably nickel or copper). Impregnation is effected by thermal decomposition of the appropriate carbonyls in contact with the graphite. The skeleton is then treated in the usual way with a solution of nickel nitrate and nickel hydroxide.

BADISCHE ANILIN- UND SODA-FABRIK. *French Pat.* 1,067,640.

### Combined Pickling and Plating Process

Interior surfaces of large steel tanks are nickel plated by filling the tank with an aqueous acid electrolyte (pH 1–4·5) of which a typical composition (g./L.) is nickel sulphate 150–500, nickel chloride 20–65, boric acid 15–45. An electrode is suspended in the tank and current is passed for at least 15 seconds with the tank as anode, thus pickling the surface. The current is then reversed, to deposit nickel of at least 0·01 in. thickness.

W. H. PRINE, assignor to INTERNATIONAL NICKEL CO., INC. *U.S. Pat.* 2,726,201.

### Bright Nickel-Plating Solution

An electrolyte which ensures levelling action and mirror-bright deposits consists of a nickel salt, a sulphonated benzopyrone (preferably 1, 2-, 1, 4- or 2, 1-benzopyrone) and at least one salt of cadmium, iron, selenium, tellurium, thorium, zinc, chromium, cobalt.

ROCKWELL SPRING AND AXLE CO. *French Pat.* 1,103, 555.

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The composition of the electrolyte covered by a related patent consists of a nickel salt, a sulphonated sulphone (preferably saccharin, diphenylsulphone, phenyl-p-tolyl-sulphone, dinaphthylsulphone, naphthalene-saccharin, disaccharin, biphenyl-saccharin, n-methyl-saccharin and methyl-bis-disaccharin), and at least one salt of zinc, cadmium and thorium. pH is preferably 1·9–5·0.

ROCKWELL SPRING AND AXLE CO. *French Pat.* 1,103,556.

### Apparatus for Plating by the Kanigen Process

Apparatus described in this patent is for large-scale deposition of nickel by the Kanigen process: it is specifically intended for use in the plating of the inside of steel tanks with nickel-phosphorus coatings containing phosphorus 3–11 per cent.

P. TALMEY and W. J. CREHAN, assignors to GENERAL AMERICAN TRANSPORTATION CORPN. *U.S. Pat.* 2,717,218.

### Nickel-Alloy Catalysts

Adipic acid is produced by treating butanediol-1·4, at 150°–300°C. and at more than 50 atm., with carbon monoxide, in the presence of particles of a nickel alloy containing iron and/or cobalt, and preferably chromium or manganese, with iodine or bismuth as activators. Examples cited include the following alloys:—nickel 95, iron 2·5, manganese 2·5, per cent., nickel 80, iron 5, cobalt 10, bismuth 5, per cent., nickel 85, chromium 2·5, cobalt 10, manganese 2·5, per cent.

BADISCHE ANILIN- UND SODA-FABRIK, A.G. *Brit. Pat.* 742, 038.

### Nickel-Alloy Steel for Sub-Zero Service

Steel containing carbon up to 0·10, nickel 2·5–3·5, titanium 0·1–0·25, per cent., iron balance, is claimed to have a high notch toughness at temperatures down to −185°C.

RHEINISCHE RÖHRENWERKE, A.G. (inventor, H. J. SCHIFFLER). *German Pat.* 932,969.

### Complex Creep-Resisting Alloys

Alloys showing high creep strength and good oxidation-resistance at elevated temperatures, e.g., 750°C., are of the following composition: carbon 1–3, silicon 0·3–1·5, manganese 0·6–1·5, nickel 7–12, cobalt 35–60, chromium 17–20, boron 0–0·5, tungsten 0–4·5, vanadium 2·4–9, molybdenum 2·9–6, niobium 1·9–5, per cent., balance iron (6·5–25 per cent.). It is specified that the total percentage of the carbide-forming elements, tungsten, vanadium, molybdenum and niobium, shall be within the limits 6·7–16 per cent., and within this range the amounts are regulated according to the relative importance of creep strength and cold ductility for specific types of service.

W. JESSOP AND SONS, LTD. (inventors, G. T. HARRIS and H. C. CHILD). *Brit. Pat.* 738,562 (similar to *U.S. Pat.* 2,713,537).

### Alloys for Precision–Cast Turbine Blades

Alloys claimed to be specially suitable for precision–cast turbine blades are within the following limits of composition:—nickel 19–50, chromium 18–30, molybdenum 8–12, boron 0·03–0·8, carbon 0·5–1·5, silicon 0–2, manganese 0–3, titanium 0–0·5, per cent., iron balance. It is specified that the iron shall be at least 10, and preferably 15, per cent.

MOND NICKEL CO., LTD. *Brit. Pat.* 739,248.

### Workable Nickel-base Heat-Resisting Alloy

A boron-free heat-resisting alloy which can be rolled to sheet or strip contains chromium 14–17, iron 8–12, molybdenum 4–7, titanium 2·25–5, aluminium 1·75–2·5, carbon 0·08–0·25, per cent., nickel balance. It is specified that the titanium: aluminium ratio shall be 3 : 2, and that cobalt up to 2·5 per cent. may also be present. The use of the alloy for turbine blades is mentioned.

ELECTRIC FURNACE PRODUCTS CO.
*French Pat.* 1,103,237.

### Steels for Exhaust Valves

Steels for exhaust valves contain carbon 0·1–0·8, silicon 0·5–2·5, manganese 0·1–3, chromium 13–25, nickel 6–20, vanadium 0·3–3, nitrogen 0·05–0·5, per cent., iron balance. The carbon + nitrogen content is specified as 0·2–1 per cent.

A.G. FÜR UNTERNEHMUNGEN DER EISEN- UND STAHL-INDUSTRIE (inventors, G. BANDEL AND K. E. VOLK).
*German Pat.* 934,836.

### Austenitic Steel giving High Yield Strength without Cold Working

British Patent 703,636 specified a precipitation-hardening steel of the following composition:—carbon 0·35–0·55, manganese 3–< 5, nickel 10–13, chromium 2·5–5·5, vanadium 0·5–1, per cent. (see *Nickel Bulletin*, 1954, vol. 27, No. 4, p. 78). A later patent extends the chromium and nickel ranges as follows:—chromium > 5·5–18, nickel 7–50, per cent.

With increased chromium, vanadium : carbon ratio is raised, in order to obtain optimum hardening effects. Manganese contents of 0·5–10 per cent. are also claimed.

THOS. FIRTH AND JOHN BROWN, LTD. (inventors, H. W. KIRKBY and C. SYKES).
*Brit. Pat.* 738,979.

### Complex Nickel-Chromium-Molybdenum Corrosion-Resisting Alloys

Corrosion-resisting alloys are covered within the following limits of composition: chromium 18–25, nickel 35–50, molybdenum 2–12, tantalum/niobium 0·1–5, tungsten up to 5, copper up to 2·5, per cent., iron balance (at least 15 per cent.). Equations interrelating the contents of the constituent metals are also claimed. A typical alloy is of the following composition: chromium 22, nickel 45, molybdenum 5, niobium 1, tantalum 1, manganese 1·5, silicon 0·5, carbon 0·05, per cent., iron balance.

W. O. BINDER, assignor to UNION CARBIDE AND CARBON CORPN. *Canad. Pat.* 516,375.

### Coating Stainless Steel for Drawing

Prior to drawing, stainless steel is coated with an aqueous slurry of the reaction product of ferrous sulphate and lime. The slurry is dried in air, on the surface of the steel, resulting in oxidation of the ferrous compound to the ferric compound.

R. M. CHRISTNER. *U.S. Pat.* 2,717,221.

### Non-Magnetic Nickel-Chromium-Manganese Steel

Non-magnetic austenitic steels showing, after precipitation hardening, a yield point of at least 40 tons per sq. in. and good ductility, contain carbon 0·3–0·9, silicon 0·2–2·0, manganese 6–20, chromium up to 8, nickel up to 12, vanadium 1–4, per cent. It is specified that the manganese + chromium + nickel shall not exceed 28 per cent., and the silicon + vanadium content is preferably at least 1·5 per cent. Specified amounts of various other elements may be present, e.g., molybdenum, tungsten, titanium, niobium/tantalum, aluminium, zirconium, cobalt, copper, boron. An example cites the following composition as suitable for non-magnetic retaining rings for electrical apparatus:—carbon 0·61, silicon 0·82, manganese 8·5, chromium 4·2, nickel 12, vanadium 3·25, per cent. A number of compositions containing about 8·5 per cent. of nickel, with manganese, chromium and other elements, are also cited.

HADFIELDS, LTD. (inventors, J. R. RAIT, T. H. MIDDLEHAM and J. O. WARD).
*Brit. Pat.* 741,053.

### Gas–Shielded Arc Welding of Nickel and Nickel Alloys

In conventional gas–shielded arc welding, small amounts of air are frequently entrained in the inert gas stream, resulting in oxidation and porosity of the weld metal. This is a particular drawback in the welding of high-nickel and nickel-copper alloys.

British Patent 649,888 claims apparatus and procedure for minimizing such contamination of the gas stream, but the procedure described is not adequate for full protection of nickel and high-nickel alloys. The present patent covers the use of a stream of inert gas which flows from a nozzle, axially round the electrode, to form a blanket over the metal in the welding zone. A laminar annular stream of hydrogen is directed to converge inwardly upon, and envelop, the stream of inert gas substantially as it emerges from the nozzle. In order to prevent turbulence in the stream of hydrogen, provision is made in the welding torch for special construction of the passages through which it is supplied.

MOND NICKEL CO., LTD. *Brit. Pat.* 742,164.

### Palladium Alloys for Soldering of Nickel Alloys

High-temperature nickel-base alloys containing at least 5 per cent. of chromium are soldered with alloys having a composition within the following range: palladium 56–10, nickel 28–72, manganese 16–40, per cent. A preferred alloy contains palladium 21, nickel 48, manganese 31, per cent.

MOND NICKEL CO., LTD., (inventors, E. C. RHODES and D. W. RHYS). *Brit. Pat.* 742,820.

### Cladding by Brazing

Clad plates are produced by placing a layer of brazing material between the base and the cladding plate, sealing the edges, applying a vacuum to the plates, and heating the composite to brazing temperature.

CHICAGO BRIDGE AND IRON CO. (inventor, R. L. BROWN). *Brit. Pat.* 740,474.

**Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.**

THE MOND NICKEL COMPANY LIMITED
THAMES HOUSE · MILLBANK · LONDON S.W.1

PRINTED IN ENGLAND *by* WIGHTMAN MOUNTAIN LTD.
WESTMINSTER, LONDON, S.W.1